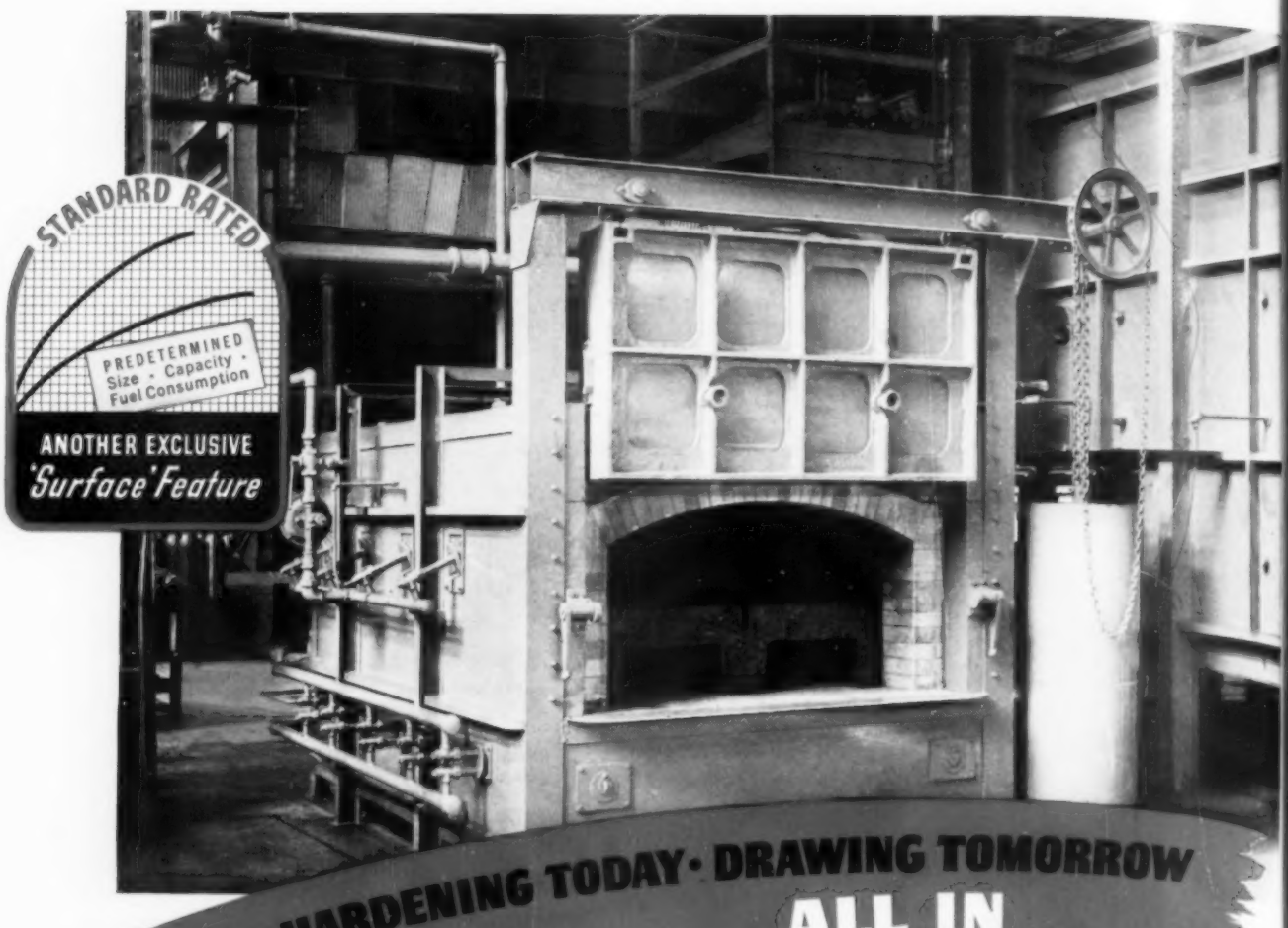
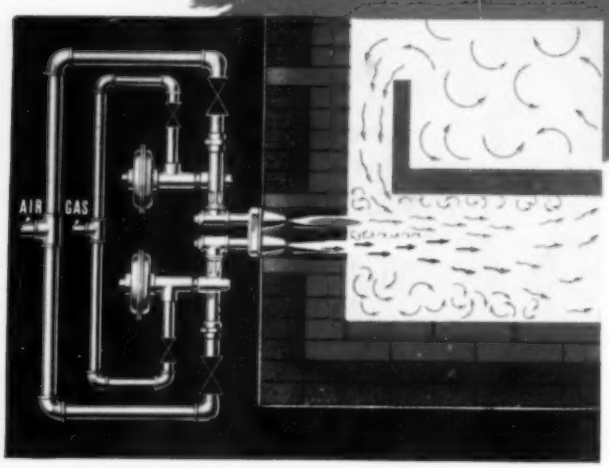
METAL PROGRESS



HARDENING TODAY · DRAWING TOMORROW ALL IN ONE FURNACE



That's versatility for you—in a Surface Combustion Standard Rated Oven Furnace. With Conjecto firing this Large Oven has a wide temperature range from 600 to 1800° F. that will fit into your present and postwar heat treating requirements whether it is for annealing, bluing, carburizing, drawing, hardening or normalizing.

Ask for descriptive literature on 'Surface' Standard Rated Large Oven furnaces.

'SURFACE' CONJECTO FIRING

. . . is accomplished by the use of twin nozzle burners, one nozzle located vertically above the other, with two or more sets of burners incorporated in a single casting. The lower nozzles are manifolded to one inspirator and the upper nozzles to another. For temperatures under 1000° F., one set operates with usual correct air-gas ratio and the other set with gas valve closed and air valve open to provide additional circulation of hot gases and more uniform heating.

For temperatures above 1000° F.—both sets operate in usual manner with proper air-gas ratio.

'Surface'

SURFACE COMBUSTION CORPORATION · TOLEDO 1, OHIO

STANDARD AND SPECIAL INDUSTRIAL FURNACE EQUIPMENT FOR:
Forging, Normalizing, Annealing, Hardening, Drawing (Direct-fired and Convection), Carburizing, Nitriding and Heating. Special Atmosphere Generators.
Write for bulletins.

September, 1945
Volume 48, No. 3

Metal Progress

Published monthly and copyrighted, 1945, by AMERICAN SOCIETY FOR METALS, 7301 Euclid Ave., Cleveland, Ohio. Subscriptions $5 a year in U.S. and Canada (foreign, $7.50); current copies $1; special reference issues $2. Entered as second-class matter, Feb. 7, 1921, at the post office at Cleveland, under the Act of March 3, 1879. The AMERICAN SOCIETY FOR METALS is not responsible for statements or opinions printed in this publication.

Table of Contents

The Atomic Bomb .. 475
By Harry S. Truman

New Developments in Aluminum Brazing .. 477
By Mike A. Miller

Metallurgical Problems in Gas Turbines .. 484
By J. F. Cunningham, Jr.

Supercharger Buckets Mass Produced by Precision Casting .. 489
By Arthur E. Focke

Critical Points, by the Editor
- Uranium 235 .. 495
- World's Largest Research Laboratory .. 495
- How Much Can a Man (or a Machine Part) Endure? .. 496
- Trend Toward Huge Aircraft .. 496
- Forging 155-Mm. H. E. Shell .. 497
- Magnesium (and Gold?) From the Sea .. 497
- Protecting Steel From Sea Water .. 498
- Want Some Magnesium? .. 498
- Izod of London .. 498

Deoxidizing a Heat of Acid Electric Steel .. 499
By Conrad C. Wissmann

Tool Life Versus Machinability of Metal .. 504-B
Data Sheet by Nelson G. Meagley

The Supersonic Reflectoscope for Interior Inspection .. 505
By Floyd A. Firestone

The Supersonic Flaw Detector .. 513
By Eric N. Simons

Correspondence
- Tool Life Versus Metal Cut, by Nelson G. Meagley .. 517
- Engineering Properties of "A" Nickel, by O. B. J. Fraser .. 517
- Lithium, the Life Saver, by Hans Osborg .. 517
- Prefabricated Houses of Aluminum, by Joan Littlefield .. 518
- Antiseptic Cutting Oils, by M. R. Wells .. 519
- Maximum Carbon in Carburized Cases, by G. K. Manning .. 519
- Ghost, found by Charles R. Wilks .. 520
- Measuring Liquid Steel's Temperature, by D. C. Gall .. 520

Personal Items .. 522, 524

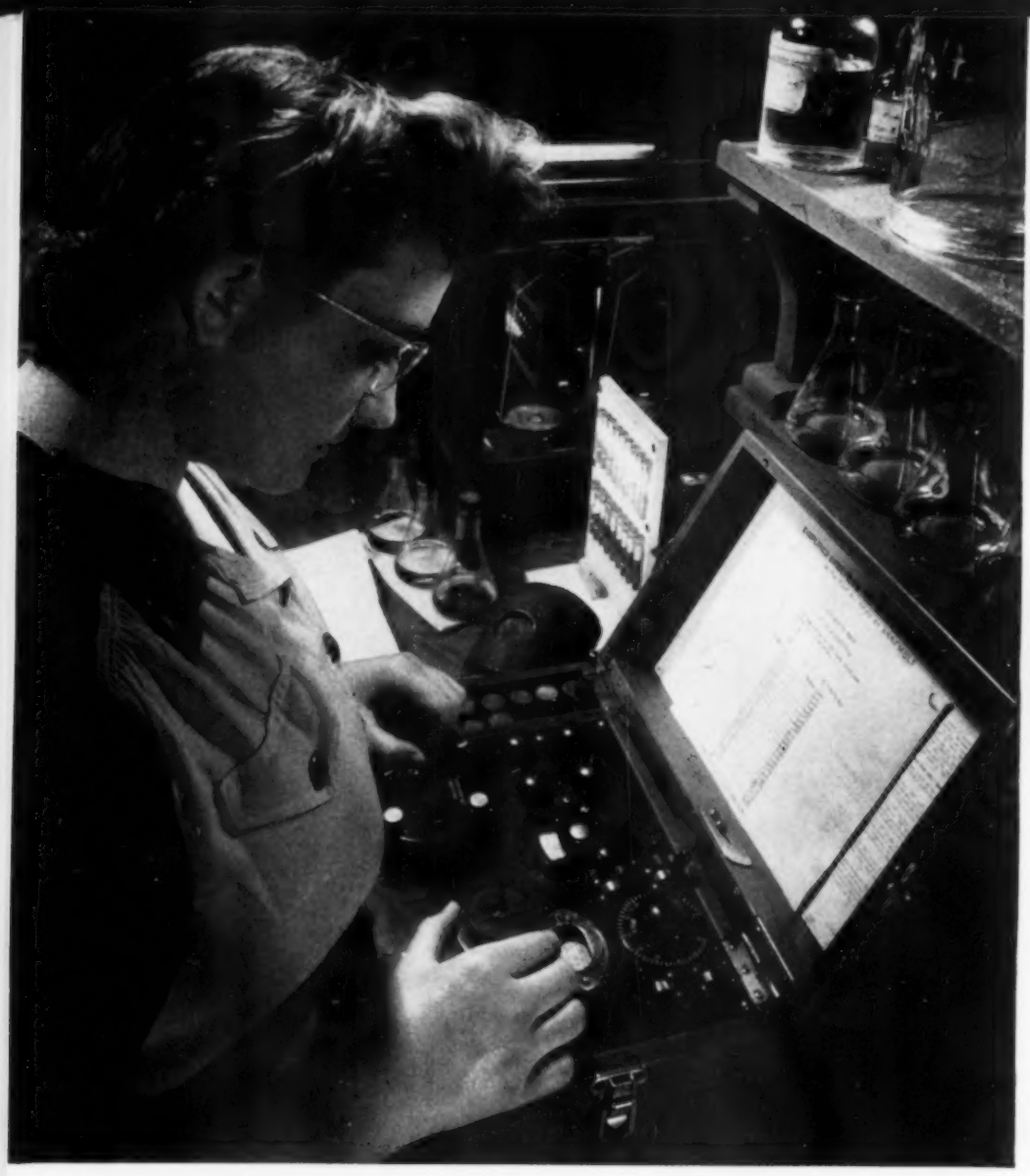
Literature From Advertisers, Free to Readers .. 532, e.s.

Advertising Index .. 614

EDITOR
Ernest E. Thum

ADVISORY BOARD
Ray T. Bayless
R. C. Dalzell
H. L. Edsall
W. H. Eisenman
C. H. Herty, Jr.
Zay Jeffries
C. D. King
C. H. Stevenson
C. E. Swartz
F. G. Tatnall
Kent R. Van Horn

Owned and Published by
AMERICAN SOCIETY for METALS



Slag tests, far faste
than chemical analyse
help Inland control th
quality of steel.

Even Slag Tells A Control Story to Inland Metallurgists

Four or more times during each open hearth heat, slag samples of many grades of steel are taken, crushed, and dispatched, through a network of pneumatic tubes, to the Inland laboratory. Within a few minutes after the receipt of each sample, a laboratory technician, using a special, fast method for determining slag characteristics that has been highly developed by Inland, dispatches the result of the slag test back to the open hearth.

Inland has turned progressive slag tests into one of the most important and useful methods for continuous control of the process of steelmaking in open hearth furnaces. Inland Steel Company, 38 S. Dearborn St., Chicago 3, Ill.

Bars • Floor Plate • Piling • Plates • Rails • Reinforcing Bars • Sheets • Strip • Structurals • Tin Plate • Track Accessories

Sales Offices: Cincinnati • Detroit • Indianapolis • Kansas City
Milwaukee • New York • St. Louis • St. Paul

INLAND STEEL

By Harry S. Truman
President of the United States

The Atomic Bomb

Beginning in 1940 before Pearl Harbor, scientific knowledge useful in war was pooled between the United States and Great Britain and many priceless helps to our victories have come from that arrangement. Under that general policy the research on the atomic bomb was begun. With American and British scientists working together we entered the race of discovery against the Germans.

FOLLOWING is the text of the statement by President Truman on Monday, Aug. 6, announcing the use of an atomic bomb for the first time in history:

Sixteen hours ago an American airplane dropped one bomb on Hiroshima, an important Japanese army base. That bomb had more power than 20,000 tons of TNT. It had more than 2000 times the blast power of the British "grand slam" which is the largest bomb ever yet used in the history of warfare.

The Japanese began the war from the air at Pearl Harbor. They have been repaid many fold. And the end is not yet. With this bomb we have now added a new and revolutionary increase in destruction to supplement the growing power of our armed forces. In their present form these bombs are now in production and even more powerful forms are in development.

It is an atomic bomb. It is a harnessing of the basic power of the universe. The force from which the sun draws its power has been loosed against those who brought war to the Far East.

Before 1939, it was the accepted belief of scientists that it was theoretically possible to release atomic energy. But no one knew any practical method of doing it.

By 1942, however, we knew that the Germans were working feverishly to find a way to add atomic energy to the other engines of war with which they hoped to enslave the world. But they failed. We may be grateful to Providence that the Germans got the V-1's and the V-2's late and in limited quantities and even more grateful that they did not get the atomic bomb at all.

The battle of the laboratories held fateful risks for us as well as the battles of the air, land and sea, and we have now won the battle of the laboratories as we have won the other battles.

The United States had available the large number of scientists of distinction in the many needed areas of knowledge. It had the tremendous industrial and financial resources necessary for the project and they could be devoted to it without undue impairment of other vital war work.

In the United States the laboratory work and the production plants, on which a substantial start had already been made, would be out of reach of enemy bombing, while at that time Britain was exposed to constant air attack and was still threatened with invasion.

For these reasons Prime Minister Churchill and President Roosevelt agreed that it was wise to carry on the project here. We now have two great plants and many lesser works devoted to the production of atomic power. Employment during peak construction numbered 125,000 and over 65,000 individuals are even now engaged in operating the plants. Many have worked there for 2½ years. Few know what they have been producing. They see great quantities of material going in and they see nothing coming out of these plants, for the physical size of the explosive charge is exceedingly small.

We have spent $2,000,000,000 on the greatest scientific gamble in history — and won.

But the greatest marvel is not the size of the enterprise, its secrecy, or its cost, but the achievement of scientific brains in putting together infinitely complex pieces of knowledge held by many men in different fields of science into a workable plan. And hardly less marvelous has been the capacity of industry to design, and of labor to operate, the machines and methods to do things never done before so that the brain child of many minds came forth in physical shape and performed as it was supposed to do.

Both science and industry worked under the direction of the United States Army, which achieved a unique success in managing so diverse a problem in the advancement of knowledge in an amazingly short time.

It is doubtful if such another combination could be got together in the world. What has been done is the greatest achievement of organized science in history. It was done under high pressure and without failure.

We are now prepared to obliterate more rapidly and completely every productive enterprise the Japanese have above ground in any city. We shall destroy their docks, their factories and their communications. Let there be no mistake; we shall completely destroy Japan's power to make war.

It was to spare the Japanese people from utter destruction that the ultimatum of July 26 was issued at Potsdam. Their leaders promptly rejected that ultimatum. If they do not now accept our terms they may expect a rain of ruin from the air, the like of which has never been seen on this earth. Behind this air attack will follow sea and land forces in such numbers and power as they have not yet seen and with the fighting skill of which they are already well aware.

The Secretary of War, who has kept in personal touch with all phases of the project, will immediately make public a statement giving further details.

His statement will give facts concerning the sites at Oak Ridge near Knoxville, Tenn., and at Richland near Pasco, Wash., and an installation near Santa Fe, N.M. Although the workers at the sites have been making materials to be used in producing the greatest destructive force in history they have not themselves been in danger beyond that of many other occupations, for the utmost care has been taken of their safety.

The fact that we can release atomic energy ushers in a new era in man's understanding of nature's forces. Atomic energy may in the future supplement the power that now comes from coal, oil, and falling water, but at present it cannot be produced on a basis to compete with them commercially. Before that comes there must be a long period of intensive research.

It has never been the habit of the scientists of this country or the policy of this government to withhold from the world scientific knowledge. Normally, therefore, everything about the work with atomic energy would be made public.

But under present circumstances it is not intended to divulge the technical processes of production or all the military applications, pending further examination of possible methods of protecting us and the rest of the world from the danger of sudden destruction.

I shall recommend that the Congress of the United States consider promptly the establishment of an appropriate commission to control the production and use of atomic power within the United States. I shall give further consideration and make further recommendations to the Congress as to how atomic power can become a powerful and forceful influence toward the maintenance of world peace.

> This revelation of the secrets of nature, long mercifully withheld from man, should arouse the most solemn reflections in the mind and conscience of every human being capable of comprehension.
>
> We must indeed pray that these awful agencies will be made to conduce to peace among nations and that instead of wreaking measureless havoc upon the entire globe they may become a perennial fountain of world prosperity.
>
> — Winston Churchill.

IN his statement, Secretary of War Stimson outlined the studies and construction program that led up to the successful manufacture of the atomic bomb, giving especial credit to the following men:

A general policy group, appointed in 1941, consisting of Vannevar Bush, director of Office of Scientific Research and Development, Henry A. Wallace, Henry L. Stimson, Gen. George C. Marshall, and James B. Conant, president of Harvard University.

In June 1942 Maj. Gen. Leslie R. Groves was appointed to take executive charge of the program, known as "Manhattan Engineer District". The committee to plan military policy consisted of Dr. Bush, Lt. Gen. Wilhelm D. Styer and Rear Admiral William R. Purnell.

"Clinton Engineer Works" near Knoxville, Tenn., were constructed under the direction of Brig. Gen. J. C. Marshall. One of the plants was designed by M. W. Kellogg Co. and is operated by Union Carbide and Carbon Corp. The other was designed by Stone and Webster and is operated by Tennessee Eastman Co. "Hanford Engineer Works" in south-east Washington was built and is operated by duPont.

The special laboratory near Santa Fe "has been planned, organized, and directed by J. Robert Oppenheimer. The development of the bomb itself has been largely due to his genius and the inspiration and leadership he has given to his associates", to quote Secretary Stimson's words. "Behind these concrete achievements lie the tremendous contributions of American science. No praise is too great for the unstinting efforts, brilliant achievements, and complete devotion to the national interest of the scientists of this country."

To coordinate American with British and Canadian efforts a Combined Policy Committee was established. Its scientific advisers, for the respective governments, were Richard C. Tolman, Sir James Chadwick and C. J. Mackenzie.

By Mike A. Miller
Assistant Chief
Process Metallurgy Division
Aluminum Research Laboratories
New Kensington, Pa.

New Developments in Aluminum Brazing

AS A COMMERCIAL PROCESS, aluminum brazing is now about six years old. First described by G. O. Hoglund in a preprint to *Research Supplement,* American Welding Society, in November 1939, the process has seen a large scale expansion so that at the present time a number of manufacturers are using one or more of the three major procedures developed for aluminum alloys, namely, torch brazing, furnace brazing and flux bath brazing. Some of the commercial aspects of the process have been discussed by Hoglund in his first paper, by A. H. McGraw in *Product Engineering,* Vol. 11, p. 176 (1940) and by H. D. Samuel in *Automotive Industries,* Vol. 89, p. 28 and 64 (1943). The results of several fundamental studies concerning the flow of the brazing alloys to form the joints have also been presented by the present writer in *The Welding Journal, Research Supplement,* Vol. 20, p. 472s for 1941, and p. 596s for 1943. Recent publications by Messrs. Hartmann, Hoglund and Miller in *Steel,* Vol. 115, p. 84 (1944) and *Transactions* of the American Society of Mechanical Engineers for 1945, p. 1, include a description of the materials available, the alloys that can be brazed, and the technique employed in the brazing of aluminum alloy products.

Aluminum brazing differs from welding in that specially developed fluxes and filler materials, having a melting point below the alloys being joined, are used for making the joints without melting the parent parts. It differs from other brazing processes in that the filler materials are aluminum alloys rather than a dissimilar metal or alloy. The parts produced are, therefore, similar to welded parts in the sense that the product is 100% aluminum alloy, a circumstance beneficially reflected in color match and appearance, strength and resistance to corrosion, and ability to be anodically coated and electroplated.

Since the operating principles have been adequately described in the literature noted above, this discussion will be limited to some of the newer developments and to illustrate a few of the current applications. Emphasis will be placed mainly on torch, furnace and flux bath procedures because they are apparently the only ones now being used in production. A few of the special techniques developed during the past few years will also be considered.

The alloy and flux designations in the following discussion are the commercial numbers of the Aluminum Co. of America. Some of the alloys, heat treatments, brazing processes and materials are covered by United States patents.

Procedures in Use

Torch brazing is very similar to gas welding in that the heat required for melting the filler material is applied locally to the joint with a welding torch which burns either oxygen and hydrogen or oxygen and acetylene. A long reducing flame is used and heat is strictly limited — only enough to melt the flux and filler alloy into the joint but not enough to melt the parent material. Previously a mixture of three parts of a special flux to one part of water is ordinarily applied both to the joint and to the wire or rod. Torch brazing the work-hardening alloys 2S and 3S and the precipitation-hardening alloys 51S, 53S and 61S is common. Certain others have been brazed experimentally, but standard procedures for them have not yet been devised. It is the present practice to use No. 716 brazing wire and No. 33 or No. 53 brazing flux.

Figure 1 shows a section through a torch brazed flange joint in 0.032-in. 3S-½H sheet, taken from a large panel which had been totally

immersed in the sea at Miami for one year. Note the excellent penetration of brazing alloy in the making of the joint and the absence of corrosion.

The strength of torch brazed aluminum alloy parts is the same as gas welded parts. The alloys and fluxes used to make these joints, which are generally of the lap or flange type, have little or no influence on the mechanical properties of assemblies in a given parent alloy, providing the design of the joints does not introduce stress raisers. This circumstance is, of course, the result of the localized heating which anneals or otherwise heat-affects a zone adjacent to the joint. Properly made torch brazed joints *always* fail in the sheet adjacent to the joint when tested in tension.

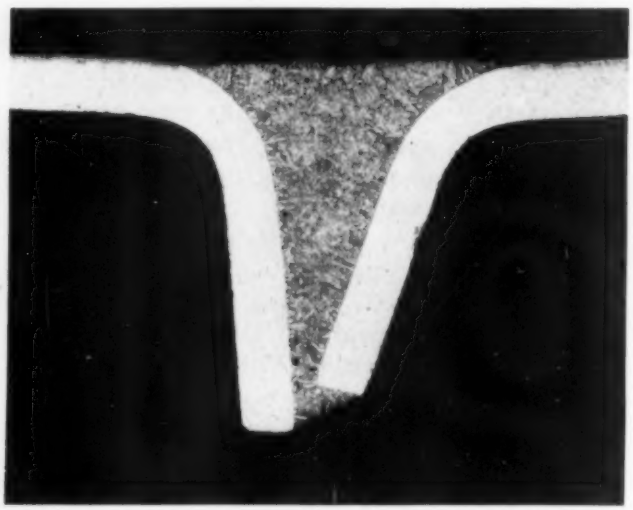


Fig. 1 — Section Through a Torch Brazed Flange Joint in 0.032-In. 3S-½ H Sheet. Magnified about 10 times. This specimen resisted corrosion of warm sea water for one year

In Table I are summarized some mechanical properties obtained for torch brazed flange joints in 0.040-in. sheet of the type shown in Fig. 1. The values average a number of specimens prepared with several different filler alloys and fluxes. Whether or not the flange is machined down to the sheet thickness, failures are outside the joint, in the sheet itself, showing that the braze is stronger than the sheet.

Table I — Mechanical Properties of Butt Welded and Flange Brazed Joints in 0.040-In. Sheet

Joint	Sheet	Treatment After Joining	Tensile Strength	Elongation
Weld	3S-½ H	As welded	16,000 psi.	21% in 2 in.
Braze	3S-½ H	As brazed	16,000	20
Weld	53S-T	As welded	22,000	7
Braze	53S-T	As brazed	22,000	6
Weld	61S-T	As welded	26,000	7
Braze	61S-T	As brazed	26,000	8
Braze	61S-W	Aged	28,000	5
Braze	53S-H	Heat treated and aged	38,000	4
Braze	61S-W	Re-heat treated and aged	45,000	6

Table II gives some flexural fatigue properties of torch brazed flange joints in several aluminum alloys. The tests were made with a special machine designed for testing sheet in flexural fatigue in constant deflection, which stresses the specimen as a cantilever beam. The flange joints were made in 0.064-in. sheet, the flange depth being 0.125 in. for 43S alloy and 0.1875 in. for No. 716 alloy. All of the specimens were tested until failure occurred, or were removed without failure after completing 200 million cycles of stress. Because of the shape of the torch brazed flange joints, the endurance limit has been defined as the maximum deflection to which the specimen can be subjected to withstand 200 million cycles without failure.

As with tensile properties, the particular brazing alloy and flux used have no influence on fatigue strength. It is seen that torch brazed flange joints in 3S-¼ H sheet have a higher fatigue strength (larger limiting deflection) than gas welded butt joints in the 3S-½ H sheet. Comparisons of the fatigue strength of the brazed joints with those of plain sheet (assuming that deflection bears a linear relationship to stress in all of the test specimens) indicate that torch brazed joints in 3S-¼ H and in 61S-W or 61S-T sheet have fatigue strengths about 75 and 90% of the respective sheets without joints.

Furnace Brazing — Because it lends itself to batch or continuous operations, which are less

Table II — Flexural Fatigue of Torch Brazed Flange Joints in 0.064-In. Sheet

Sheet	Type of Joint	Filler Wire	Flux	Treatment After Brazing	Fatigue Limit Deflection
3S-½ H	Gas welded butt	2S	No. 22	As welded	0.075 in.
3S-¼ H	Torch brazed flange	43S or No. 716	No. 53	As brazed	0.090
61S-W	Torch brazed flange	No. 716	No. 33 or 53	As brazed	0.145
61S-T	Torch brazed flange	No. 716	No. 53	Artificially aged	0.135

Fig. 2 — Gasoline Drum; Application of Brazing Alloy and Flux to Head and Chime Ring Prior to Loading Drum-Half Into Brazing Furnace

dependent on the individual training r skill of the operator, furnace brazing is used wherever the shape and design of parts permits. This is reflected in savings in operational and finishing costs. In addition, parts can be so made that are impossible by other techniques. Several examples will serve to illustrate these important advantages.

First may be selected a gasoline drum to illustrate a light weight article in which furnace brazing is one of the methods of fabrication. The chime rings of this 61S alloy drum are furnace brazed to the drawn halves by No. 716 brazing wire and No. 33 brazing flux before the two halves are gas welded in a central girth seam to form the completed unit. Brazing alloy and flux are placed on these chime rings by the operators prior to loading into the furnace, as shown in Fig. 2. The brazing temperature of 1080 to 1090° F. is, in addition, a heat treating operation for the 61S alloy.

Figure 3 shows the structure of the chime ring joint; the soundness and the alloying of sheet and brazing alloy are apparent. The brazing alloy was placed at the right and flowed completely through the joint, by capillary action, to form a smooth fillet on both sides.

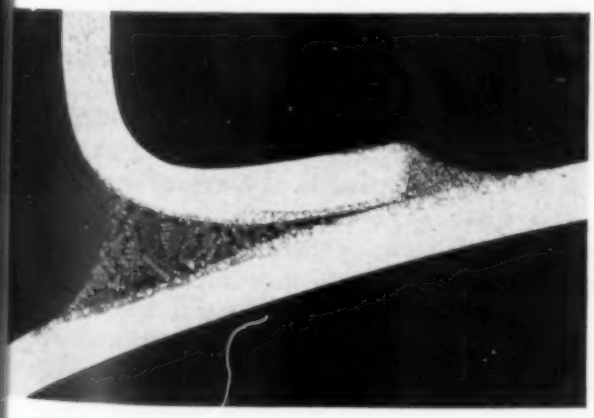


Fig. 3 — Section Through the Furnace Brazed Joint of the Gasoline Drum. The brazing alloy was placed at the right and has flowed through the entire joint. Magnified about three times

This gasoline drum, by the way, was developed by Alcoa engineers for the Army Air Transport Command's China-Burma-India run, over the "hump". It is 30 lb. lighter than the conventional drum.

Figure 4 shows a finned auxiliary water still, before and after brazing, the joints of which result from the brazing alloy supplied by the No. 12 brazing sheet fins, band, and center ring. ("Brazing sheet" is aluminum alloy sheet with a coating of brazing alloy, metallurgically bonded — in fact, a special class of "clad" sheet.) It is difficult to visualize how this unit could otherwise be fabricated. It also illustrates the important principle of self-positioning or self-jigging. This matter has been well covered by H. M. Webber for the copper brazing of ferrous alloys in reducing atmospheres. (See General Electric Co's. Publication 3193-A, reprinted from Mr. Webber's series of articles in *The Iron Age*, Sept. 8, 1938 to April 6, 1939.)

The situation with aluminum brazing is quite similar. Basically, there are three methods of

positioning parts for brazing, namely, *(a)* self-locking or self-aligning, *(b)* riveting, spot welding or torch tack-welding, and *(c)* jigs or fixtures. All of these methods have been employed commercially.

Flux Bath Brazing — Little has been said in the past about the important flux bath brazing, yet experimental work has been going on for a number of years. No flux is applied to the parts prior to heating since the bath itself is composed of the appropriate flux; it also supplies the necessary heat. The cleaned parts are assembled and the entire assembly, or some part of it, is dipped into a bath of No. 53 brazing flux held somewhat above the melting point of the filler material but below the melting point of the parent material.

Fig. 4 — Finned Auxiliary Water Still, Before and After Brazing. Illustrates the use of grooving, tack welding, and gravity-positioning for obtaining a fixture-free unit ready for loading in the furnace. Brazing alloy is obtained from No. 12 brazing sheet fins and band. About ⅓ size

A lower cost flux, No. X34, having the same brazing characteristics as No. 53, has recently been available and is expected to increase the use of this new process. (This new flux can also be used for furnace brazing.) Interesting economies are found where the design of parts permits drainage of molten flux. As pointed out by the present author in his previous publication in *The Welding Journal* for 1941 (p. 472s), the flow of alloy is assisted by the buoyancy action of the flux when flux bath brazing is used, and this effect can be of considerable importance for certain types of joints.

Flux bath brazing has been used by McQuay, Inc., to fabricate a compact air-to-air aircraft intercooler, a detail of which is shown in Fig. 5. This unit is assembled from No. 12 brazing sheet and is brazed in a few minutes by dipping into No. 53 brazing flux at 1140 to 1160° F. The view shows some of the joints between tube sheet and header plate, and the uniformity of metal flow and symmetry of fillets is apparent. This intercooler is sand blasted, after cleaning, to give a frosted finish.

Figure 6 shows three parts of an aircraft item in stages of assembly in a nickel wire rack, prior to flux bath brazing. This figure illustrates a simple method of obtaining self-positioning. The brazing alloy used for this application is No. 719 brazing wire and is applied to the joint as a wire ring.

At the present time, brazing in No. 53 brazing flux baths is carried out in internally heated, ceramic-lined pots. Linings of carbon bricks, if they do not interfere with current distribution, or high alumina bricks are preferred. Alternating current utilizes the electrical resistance of the molten flux for generating heat. Electrodes are commercial nickel or certain nickel alloys. Chromium-iron or other ferrous alloy electrodes are unsatisfactory because of excessive iron pick-up in the flux bath. Small amounts of iron or other heavy metal impurities can be removed during the so-called dehydration or drying procedure with coils of aluminum; otherwise, these impurities will deposit on the work and seriously interfere with brazing.

Assemblies, particularly large ones, or parts of varying section thickness should be preheated prior to dipping, usually at 800 to 1000° F. If the parts are assembled from thin gage brazing sheet, preheating time and temperature should be at a minimum.

Metal bath brazing as applied to aluminum alloys is still in the experimental stage. The process may be used in two ways, either as two separate baths or as a two-layer bath. The molten brazing alloy forms one bath or layer and an appropriate molten flux forms the other bath or layer. With separate baths, the parts are immersed first in molten flux and then in molten brazing alloy. If a two-layer bath is used, the parts are immersed through the flux layer into the metal layer and are then withdrawn through the flux layer. Difficulties arise from the rapid dissolution of the parts by the molten alloy, and from flux entrapped during the short cycle. At

Fig. 5 — Close-Up of Some of the Joints, Tube Sheet to Header, in Aircraft Intercooler, Flux Bath Brazed. Uniformity of fillets formed by flow of brazing alloy from brazing sheet is apparent. This unit is sand blasted after cleaning to give a frosted finish. About three times natural size

the present stage of the art, flux bath brazing is a much more desirable procedure.

Induction Brazing — The principles of induction heating have been described in a number of recent publications; see especially W. M. Roberds' article on "Practical Aspects of Induction Heating" in *The Iron Age*, Vol. 154, No. 8 (1944), p. 50. Briefly, a high frequency current, generated in a rotary converter or an oscillator, is induced in the work from similar currents carried in a water-cooled coil of copper tubing surrounding, but not touching, the work. The heating effect is concentrated in the surface of the work and progresses toward the interior by conduction only; temperature and depth of penetration are controlled by the manner and duration of current application.

Inductor coils are always formed around the work in such a manner as to induce heat in the required area or areas of the parts (which may be of any shape) without affecting adjoining sections. This has been widely applied to the heating of the ferrous alloys and the process has proven very satisfactory for brazing these materials. It is claimed that, since the heat is generated within the metal itself and can be precisely controlled, the brazing alloy penetrates completely throughout a joint. Special fixtures are required for the brazing of complex assemblies with joints of an irregular nature.

Roberds points out that because aluminum is a good electrical and thermal conductor, the brazing of aluminum alloys must necessarily be a process of relatively low electrical efficiency. Its low melting point, coupled with the tendency of the heat to concentrate at corners and other surface irregularities, requires careful design and placement of inductor coils. Best results will be obtained when the joint is circular or elliptical. Doubtless the convenience and speed of induction heating would justify its use for aluminum brazing in special applications.

Table III — Depth of Penetration of Induced Current, Inches. (Roberds)

Material	Kilocycles		Megacycles		
	10	100	1	10	100
Steel (cold)	0.008	0.003	0.0008	0.0003	0.00008
Copper	0.025	0.008	0.0025	0.0008	0.00025
Aluminum	0.035	0.012	0.0035	0.0012	0.00035
Brass	0.055	0.018	0.0055	0.0018	0.00055
Steel (hot)	0.240	0.075	0.0240	0.0075	0.00240

Table III, taken from Roberds' paper, shows the depth of penetration of induced currents for several materials, that is, the depth below the surface where the current density is reduced to about 37% of that at the surface.

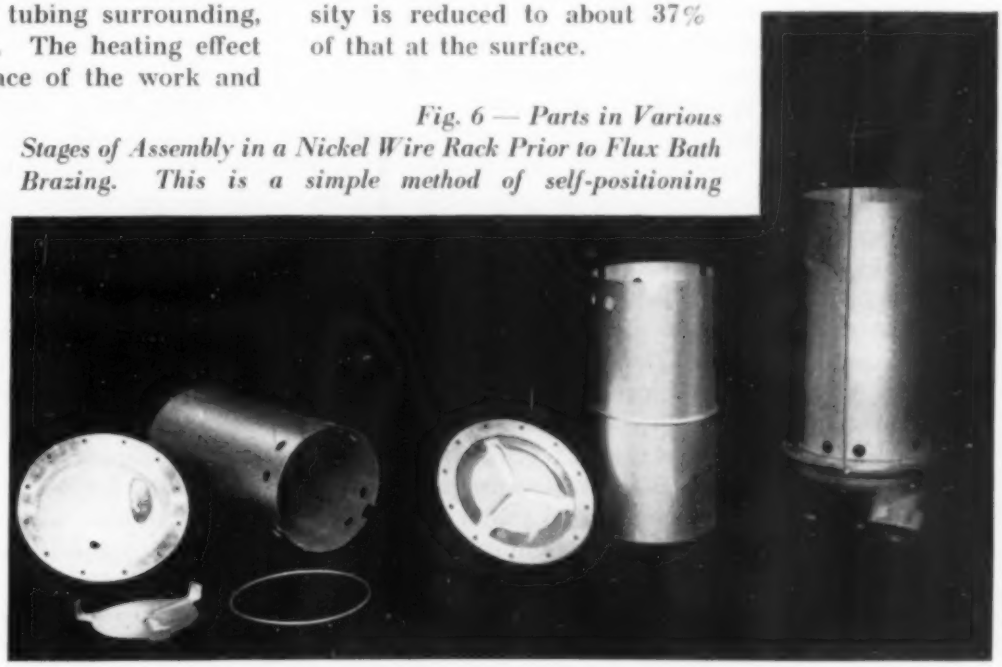


Fig. 6 — Parts in Various Stages of Assembly in a Nickel Wire Rack Prior to Flux Bath Brazing. This is a simple method of self-positioning

New Materials Available

Brazed Castings — The brazing of aluminum castings and of assemblies containing them is still the subject of considerable experimental work. Aluminum casting alloys, as well as the wrought alloys, must be brazed with filler materials which are completely molten below the solidus temperature of the parts to be joined. As is well known, the melting range of many casting alloys is lower than that of the wrought alloys which are most readily brazed. This poses some difficulty in joining castings to plate, for example. Cast aluminum-manganese alloy, No. 406, can, however, be brazed with the same facility and materials as the wrought alloy 3S. The aluminum-silicon alloy, No. 43, if cast in sand or permanent molds, can be brazed with No. 719 brazing alloy at 1040 to 1060° F.

Some of the aluminum-zinc-magnesium casting alloys, which are capable of developing high strengths by room temperature aging, may also be brazed (when in the form of sand and permanent mold castings) with No. 713 brazing sheet and No. 716, X-717 and 719 brazing wires, as well as to No. 11, 12, 21 or 22 brazing sheet parts, without adverse effect on the desired mechanical properties.

Heat-Treatable Brazing Sheet — The present writer contributed an article on "Aluminum Brazing Sheet" to *The Welding Journal's Research Supplement* (1943, Vol. 22, p. 596s). This material consists of an aluminum alloy core with a brazing alloy coating, on one or both sides, metallurgically bonded to the core.

The mechanical properties of the various older types of brazing sheet, after having passed through the brazing operation, are substantially those of annealed 3S alloy — that is, a tensile strength of about 14,000 to 16,000 psi. and an elongation of 20 to 30% in 2 in. Two entirely new brazing sheets are now commercially available, known as No. 21 and 22. These materials are susceptible to precipitation hardening, if quenched from the brazing operation and subsequently aged at an elevated temperature.

Table IV lists some of their mechanical properties. As can be seen, brazed joints can now be made with properties, after suitable heat treatment, having a level of strength considerably higher than can be obtained with the earlier brazing sheet.

To determine the shearing strength of brazed joints in No. 21 brazing sheet, ⅛-in. lap joints of a special design were prepared by flux bath brazing in No. 53 flux at 1120° F. Shearing strength was found to be about 14,000 psi. in the as-brazed condition, and about 18,000 psi. after aging for 6 hr. at 355° F.

The "flow" of brazing alloy from No. 21 and 22 brazing sheet is quite similar to that from No. 11 and 12 brazing sheet except that the maximum temperature should not exceed about 1120° F. and time kept at a minimum. If "over-brazing" takes place — that is, parts are subjected to high temperatures and long times — the mechanical properties will suffer; elongation (ductility) of the brazed parts decreases rapidly with increasing degree of over-brazing.

Table IV — Typical Mechanical Properties of No. 21 and 22 Brazing Sheet

Treatment	Temper Designation	Tensile Strength	Yield Strength	Elongation
As rolled; full hard	—H	28,000 psi.	26,000 psi.	4% in 2 in.
Annealed at 750° F.	—O	17,000	7,000	28
As quenched from brazing	—W	25,000	12,000	15
Aged after brazing	—T	35,000	29,000	9

A New Brazing Wire — It must be emphasized that for brazing wire, in contrast to brazing sheet, the solidus temperature, and by this is meant the temperature of beginning of melting, is generally no measure of the usefulness of the alloy unless it is not far below the liquidus, or the temperature of complete melting. No. 716 brazing wire, for example, begins to melt below 1000° F.; it is not completely molten, however, until a temperature of about 1090° F. is reached. The brazing temperature to be used with this alloy is 1080 to 1090° F., that is, in the range of greatest amount of liquid phase. Furnace or flux-bath brazing at lower temperatures will produce "skeletons" — that is, residues of the high-melting components of the added filler metal — in assemblies which do not permit the brazing alloy to puddle by gravity into the joints. (This is of some use in torch brazing in permitting greater lap penetration and easier control of the operation.)

The use of No. X717 brazing wire in the range of 1080 to 1090° F. has already been mentioned in connection with brazing certain castings. This wire can also be used on the wrought alloys 2S, 3S, 53S and 61S. Joints made with this alloy have a good corrosion resistance. For example, torch brazed flange joints in 61S-T made with No. X717 brazing wire exhibited no loss in tensile strength after two years in 3½% sodium chloride intermittent spray, or after three

years exposure to a marine atmosphere at Point Judith, R. I. In testing, all the joints broke in the sheet. No. X717 brazing wire produces torch brazed joints of the same strength as gas welded joints made with 43S — for example, about 26,000 psi. tensile strength for brazed joints in 61S-T sheet.

Brazing Paste — Brazing alloy is commonly supplied to the joint by placing wire rings, washers or strips in correct positions, or from the coating on aluminum brazing sheet. For furnace or induction brazing the brazing alloy may also be supplied to the joint in a comminuted form. Brazing paste, a mixture of brazing alloy, flux powders and a liquid vehicle, is especially desirable when the joints are in a vertical plane or when the material must be applied underneath a joint. Upon baking, the paste hardens and remains in position until sufficient heat is applied to melt the ingredients and cause the alloy to flow into the joint by capillarity. Because of this feature, brazing paste can be used to make "upside-down" joints.

Special Techniques Developed

Furnace Atmosphere — In contrast to the furnace brazing of ferrous metals with copper in special reducing atmospheres, the furnace brazing of aluminum with aluminum-base alloys is carried out in ordinary air atmospheres, since the so-called reducing atmospheres are *not* reducing to aluminum oxide, and it is necessary to flux the oxide from the surfaces to be joined and from the brazing alloy, as well as to protect these surfaces from further oxidation. The actual atmosphere in contact with the hot metal is not ordinary air, however, but a complex and variable mixture of unburned oxygen, nitrogen, moisture from the atmosphere and the flux, and acidic halide gases from the flux.

A rather serious consequence of this moist halide acid atmosphere is the scaling of electric heating elements, radiant tubes, rollers, conveyer belts, hearth plates, baffle plates, fan blades, jigs and fixtures. Replacements of such parts may be an important cost item. Some experience indicates that a little crushed limestone, placed in a strategic position, will minimize the corrosive attack by removing some of the acid gases. Although experience to date is very limited, the amount of scaling can be reduced to one-half or less in this way. The furnace design should incorporate limestone or similar alkaline materials in the best possible location to react with the acid components of the atmosphere, and to change its atmosphere rather frequently.

Brazing Stop-Off — In a number of brazing applications, it is desirable to restrict the flow of molten flux and alloy. For example, a capillary (such as a groove) may be present near a joint or connected with it and the brazing alloy must be kept out. A special stop-off material can be applied to the groove for this purpose when furnace brazing. A different stop-off material is available for restricting metal flow in flux bath brazing, and the latter may also be used to protect jigs and fixtures during immersion in molten flux.

Flux Residues — A rather interesting method has been devised for determining whether all the flux has been removed. It consists in thoroughly drying the cleaned, brazed part and then applying a paste or slurry consisting of 100 parts by weight of precipitated chalk, three parts by weight of methylene blue or carmoisine dye, and a suitable amount of carbon tetrachloride. The vehicle evaporates rapidly at room temperature to leave a thin white or pale pink film. If brazing flux is present, for example, in minute pores in a fillet, deep blue or bright red spots, depending on the dye, appear in the film after 5 to 30 min. The test applies to all of the standard brazing fluxes, No. 30, 33, and 53. After the test, the film is removed by flushing with water or, better, by a brief dip in dilute nitric acid followed by rinsing and drying.

Advantages and Economies

There are three major sources of economy in the aluminum brazing process.

First, parts too thin or too complex to be welded or otherwise fabricated may be satisfactorily brazed. For example, it is ridiculous to consider gas welding parts in 0.006-in. thick aluminum alloy, formed into a complicated shape such as a corrugated sheet heat exchanger, which may have thousands of linear feet of joint. Assuming that this thin material could be gas welded and that the joints were accessible, no conceivable welding rate could compete with the few minutes required to *(Continued on page 528)*

By J. F. Cunningham, Jr.
Applications Engineer
Elliott Co.
Jeannette, Pa.

Metallurgical Problems in Gas Turbines

JET propulsion is now a matter of intense news interest because of its application to speedy fighting aircraft, flying faster than any propeller could drive them. This interest should naturally carry over into the field of gas turbines, for gas turbines are a fourth member of the family of prime movers, only recently coming to take a proper place alongside steam engines, steam turbines and internal combustion engines, the other three members of the family. The connection between jet propulsion and gas turbines is natural, for the jet plane's power plant must include an air compressor, and this is driven by a gas turbine. It is also true that the superchargers for internal combustion engines used on all modern aircraft are merely gas turbines powered by the cylinder exhausts.* Rather than discuss these features, the present article will say something of the development of a gas turbine power plant for ship propulsion, a joint project of the Elliott Co. and the U. S. Navy, Bureau of Ships, whose aim is to convert as much as possible of the energy in unburned liquid fuel into shaft horsepower — a "prime mover" in the true sense of the word, not merely an auxiliary or a machine for converting a little waste heat into useful work. Such a gas turbine power plant is still a novelty, whereas gas turbines are now an engineering commonplace.

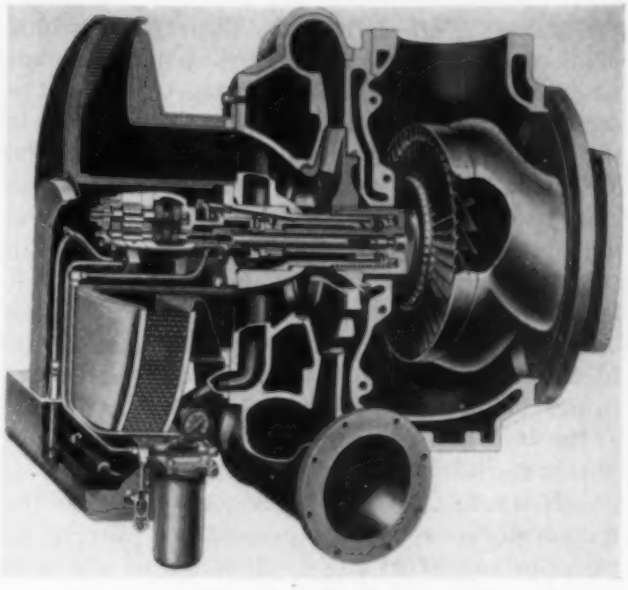
It is no trick to build a turbine for operation on air or other gases instead of steam. The Elliott Co. has made hundreds of such mechanical drives using natural gas, and they are in operation throughout the oil country. These operate at temperatures and pressures less severe than encountered in modern steam plants. Numerous turbines of the type pioneered by Brown-Boveri of Switzerland have been used in the petroleum refineries. Five years ago we built a turboblower for a gasoline cracking plant, and it was designed for operation on gas at 850° F., a conventional temperature in this industry. The diesel supercharger is one step closer to the gas turbine power plant. Some 1300 of our units have been put into heavy-duty service on four-cycle diesels in marine, rail, and stationary applications. As opposed to aircraft superchargers having limited life, they are designed to operate continuously for 100,000 hr. They represent such an important preliminary phase of our gas turbine development that I would like to make some comments on their construction.

A cutaway section of the turbocharger is shown in Fig. 1. The general arrangement is a single-stage turbine wheel mounted at the right end of the shaft that carries a cast aluminum blower impeller (shown in section somewhat toward the right). The assembly includes a complete lubrication system and an intake silencer. Exhaust gases from the diesel engine cylinders are directed into the turbine wheel. These gases, at temperatures up to 1020° F., are separated by a matter of a very few inches from the blower assembly which operates at perhaps 160° F. The blower delivers compressed, cool air directly to the intake manifold of the engine. The proximity of the high temperature turbine wheel and casing to the parts operating at more nearly ambient temperature poses many difficult problems of mechanical construction and cooling met by the use of a water wall partition between the turbine and blower casing and a supply of cooling oil to the shaft and bearings. (Note that the inboard bearing is located virtually within the turbine housing.)

One look behind the insulation of a gas

*A comprehensive discussion of these aspects of gas turbines and jet propulsion is contained in an article on "Jet Propulsion" in *Metal Progress* for September 1944.

Fig. 1 — Phantom View of Supercharger for Heavy Duty, Four-Stage Diesel Engines



turbine in operation reveals metal which would ordinarily be considered ripe for the blacksmith's hammer. The metallurgist's problem is immediately apparent.

The third major requirement is a means of compressing large volumes of air economically. Probably the most obvious feature of a gas turbine plant is the compressor and the relatively great power required for compression. Rotary machines for this purpose have proven a stumbling block for many years, which has now been surmounted by two designs, the axial flow compressor (which is a turbine running backward) and a centrifugal compressor (which is similar to a Francis water wheel reversed). Our company prefers the latter, especially in the form developed by Alf Lysholm of the Swedish firm, Ljungstroms Angturbin. Metallurgists may recognize it as an adaptation of the Roots blower, wherein two-lobed impellers mesh into each other as they rotate. The Lysholm compressor has two multi-lobed rotors developed into intermeshing helixes; its efficient operation demands the highest precision in rotors, casing, bearings and gear drives.

While running at the high speed characteristic of turbomachinery, it inhales successive bites of air which are enclosed, cut off and compressed by squeezing, and finally pushed out into the exhaust system. At both the intake and exhaust the successive bites overlap so that a continuous flow is obtained.

Operating Principles

Perhaps the first question that rises in connection with this development is "Why must a gas turbine run so hot?" The answer is that the output of the gas turbine plant is determined by the difference in temperature level between the expansion of the gas in the turbine, and the compression of the gas in the compressors.

If we had ideal, perfectly frictionless compressors and turbines without any losses, we could compress air in the compressor and expand it in the turbine. The turbine would just drive the compressor, but there would be no power left over for useful work. With such perfect machinery we would find, however, that as soon as we raised the temperature of the compressed gas before expanding it, we could get useful work out of the machine. We would then have an ideal gas turbine operating as a prime mover. The more we raised the temperature of the compressed air, the more work we could get out of a given flow.

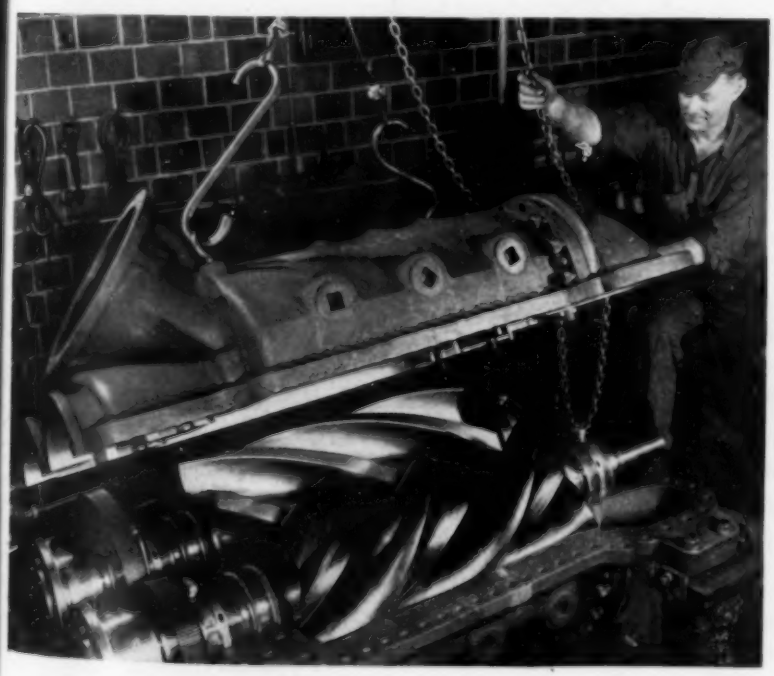


Fig. 2 — Elliott-Lysholm Centrifugal Air Compressor; Upper Casing Removed. As the rotors turn, the male and female lobes intermesh and compress the air until finally the discharge port is uncovered and the air squeezed out in rapid overlapping bites, producing a steady flow of compressed air. The quantity of air is directly proportional to the speed of rotation and is independent of discharge pressure. This machine is rated at 12,500 cu.ft. per min.

A real (rather than the ideal) gas turbine plant operates the same way; but since real machinery has losses, it is necessary to raise the temperature of the air in order to compensate for these losses. In other words, there must be a considerable difference in temperature level in compressor and combustion chamber before the machine starts to turn over. The more we can raise the temperature of the compressed air before expanding it, the more work we can get out of a given rate of air circulation, and the higher the efficiency of the plant — all other things being equal. Thus, we strive to operate at the very highest temperatures which the available materials can withstand with reliability.

It would appear to be very easy to raise the temperature of the compressed air merely by injecting some fuel into it. It would be if it were not for the requirement that this combustion take place in a space comparable to the cylinders in an internal combustion reciprocating engine. This means we must produce combustion chambers having very much higher heat release rates than obtained in boiler fire boxes, for example. As shown at top of Fig. 3, this combustion chamber is a simple right angle in a pipe line and has no inner shell separating combustion air from cooling air. The entering air flows naturally into a double vortex which completely burns the partially burned fuel and air mixture issuing from the cast cone at the inlet end.

Not all of the temperature rise of the compressed gas need be obtained by burning fuel; in fact, for an efficient gas turbine plant some must be obtained from the hot exhaust gases leaving the last turbine in the set returning this heat to the incoming air in an air preheater or regenerator. Efficiency in this regeneration is secured by packing a number of thin-walled, finned nickel tubes of air-foil cross section in the heat interchanger; hot exhaust gases flow around the tubes, compressed air flows through them.

Metal Requirements

It is now obvious that one of the major problems in designing a successful gas turbine plant was that of finding suitable materials for operation at the high temperatures required for a thermal efficiency comparable to that of a steam turbine or diesel engine. Let us examine the temperatures encountered throughout the cycle of the Elliott gas turbine plant.

A schematic cycle showing the maximum temperature at each major stage is presented in Fig. 3. It will be noted that two machines — a high pressure turbine and a low pressure turbine — and a considerable part of the duct work operate at red heat. The physical characteristics of metals at these temperatures present a most difficult problem in themselves.

Not only is the ten-

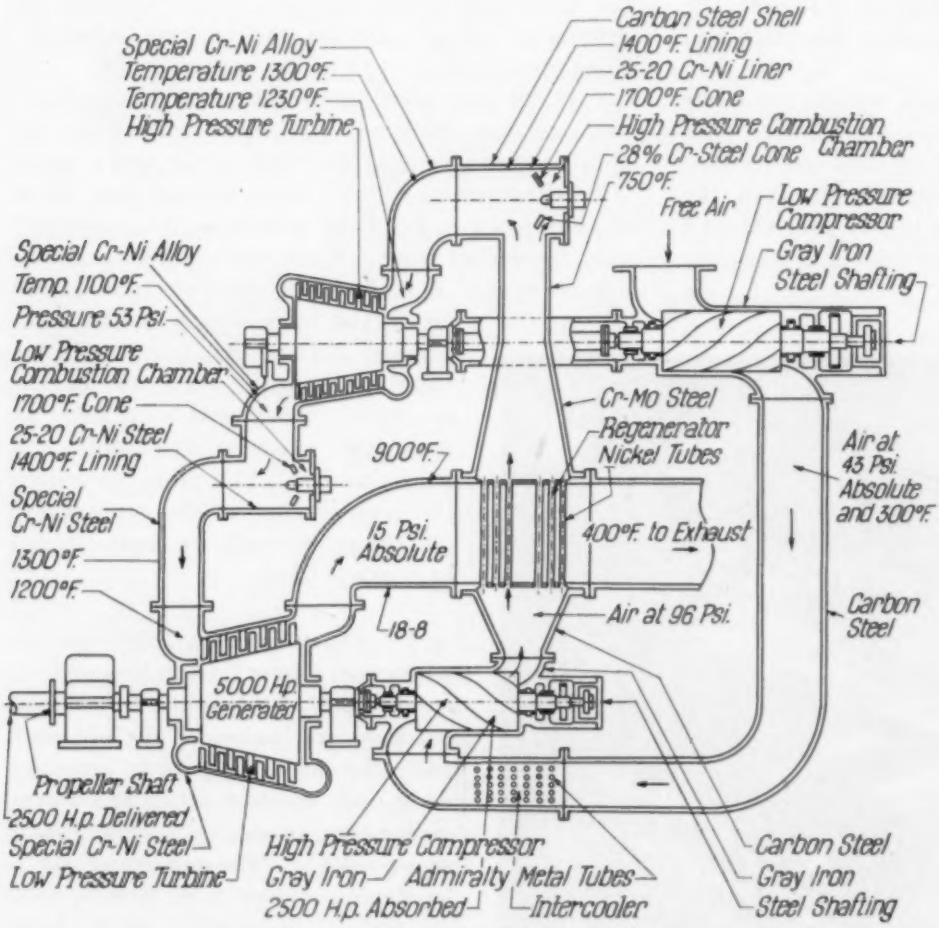


Fig. 3 — Diagram of Elliott-Lysholm Gas Turbine Cycle for Ship Propulsion, and the Temperatures and Materials of Construction of Important Parts

★This is the energy of the jet in a jet-propelled aircraft; its recovery by a good heat interchanger has the greatest single effect of any detail in raising the efficiency of the turbine plant.

sile strength of the metal reduced at high temperatures, but also the phenomenon known as creep becomes apparent at prolonged exposure. Creep exhibits itself as a growth or elongation of the material when subjected to load, and the rate at which it takes place is governed by the material, the load applied, and the temperature.

Because of creep it is certain that, after some period of operation, the turbine rotors will grow, the flat sided ducts will bulge, and the round ducts will grow too large in diameter and too thin in wall. It is the designer's problem to choose materials and loadings of such character that these changes will not be obnoxious before a certain definite time in terms of hours of operation. The present plant is designed for 10 years of continuous high temperature service.

Such long periods of time involve actions that do not occur in ordinary equipment. As yet little precise information is available on the endurance of steels to alternating loads at such temperatures, especially as affected by surface changes due to corrosion or erosion.

Figure 3 also shows the materials used in all major parts of the plant. As will be seen, a fair gamut of materials has been run on this job. Expansion effects are intensified by the fact that so much of the high alloy has a coefficient of expansion half again as large as plain carbon steel. For example, the turbines are nearly ½ in. longer when operating than when cold. The problem of foundations and connections is therefore a serious one. Both turbines are fixed at their exhaust ends, with all expansion forced toward the inlet, where the connections "float" by freely moving links. Relative movement between turbines and driven machines is absorbed by double flexible coupling and long torque-tube jack shafts. To minimize heat losses, connections between hot and colder casings are made with the smallest areas of contact. Great care in design, to avoid undue changes in metal section, is also necessary. All main members are tied together with radial pins which permit free movement between adjacent parts — a "heat elastic" construction. In order to disjoint contacts between the high alloy steels — materials of notorious tendency to seize or gall — a special colloidal silver dope has been compounded.

The nickel toroidal joints in the high pressure combustion chamber inlet brought up the important problem of *workability* of the materials. This duct is made of chromium-molybdenum steel to operate at temperatures up to 1000° F. The toroidal joints are spinnings, 0.025 in. thick. If made of chromium-molybdenum steel, they would scale under operating conditions, and this would be dangerous in a part already of minimum thickness. Austenitic stainless steels have a higher coefficient of expansion than chromium-molybdenum, which would cause intolerable differential stresses; and ferritic stainless steel cannot be spun successfully. Copper alloys have high coefficients of expansion and very poor high temperature properties. Commercial nickel usually work-hardens so rapidly it is impracticable to spin it, but at our request a special grade of nickel was produced which could be spun.

The use of high temperature materials creates so many manufacturing problems that the only possibility of successful construction comes through extremely close cooperation of the manufacturing and design departments. Castings, though simple and convenient to design, are hard to produce in high temperature alloys. Sometimes they do not have high temperature properties of rolled or forged material of the same analysis. Because riveted joints depend primarily on tension in the rivet, they can be used only in minor attachments.

In general, the best recourse is to rolled plate joined by welding, and by this method to fabricate as many pieces as possible into one permanent single assembly. This was done in all of the duct work and the combustion chambers. The turbine rotors were machined from rolled plate and forgings, welded into an assembly.

The extended use of welding brings up some interesting problems in these materials fit for high temperature service. As an instance, S.A.E. 4130 chromium-molybdenum steel is an air hardening variety. There is considerable danger that when a weld is made the heat of the weld will cause an extremely hard, brittle zone directly adjacent to the weld. This characteristic is more pronounced in heavy material than in light, due to the quicker cooling of the welds. As a result, it is necessary to determine whether or not preheating is required for each type of joint, and if so, how much.

The welding of 19% chromium, 9% nickel steel containing tungsten and molybdenum was a completely new problem. No engineered welding had been done on this alloy prior to the design of this gas turbine plant, as far as we could discover. It was necessary to develop a special electrode, since the existing ones recommended for high alloy were found to be short of the necessary strength at high temperature. Not only did the new electrode have to possess strength but tests were necessary to ascertain the operating characteristics of the electrode, as there were some very difficult welds on the job.

Extended tests were then made as to the best procedures to use in laying weld metal. Trouble was encountered with cracks in the welds, which was found to be a matter of analysis of the core wire. Without going through all of these stages, there would have been little chance of building the high and low pressure rotors for the turbines in this plant.

Rotors for the large Lysholm compressors needed steel shafts. However, steel was not a good material for the rotors themselves. This set up a problem of attaching the steel stub shafts into the cast iron rotors. A number of methods

Fig. 4 — Assembly of Single Rotor Disk, Blades and Shrouding, Prior to Shrinking on Shaft

were studied, but the most advantageous from the point of design appeared to be silver soldering. While this is a well-known process used very extensively on small parts, tests had to be made to learn under what circumstances predictable joints could be made in these large parts. As a result of these tests, the brazing material was properly placed, a method of cleaning and fluxing the material was developed, and a heating cycle set up which assured success.

Again, in the manufacture of the regenerator, a large number of joints were needed which would transmit heat from the tubes to the fins. Some idea of the number of joints can be realized from the fact that in this regenerator there was over 8½ miles of nickel tubing. These joints had to be of such a type as to remain strong at a temperature exceeding 1000° F., the expected maximum of the exhaust gases. With considerable testing and numerous changes a method was developed for building these regenerators from nickel tubing and sheets by a copper brazing. The copper is a good carrier of heat and the joint is relatively inexpensive to make; likewise when the brazing job has been completed (in a reducing furnace atmosphere) the parts are clean and free of scale of any kind.

Probably the most unusual welding job was the fabrication of the turbine rotors. Each of the 15 rotor disks was completely machined and the forged and finished blades were attached and shrouded as shown in Fig. 4 prior to assembly on the shaft. These disks were then heated in hot water and shrunk on the shaft. When the rotor had been completely assembled with the shaft in the vertical position, four tack welds were made in each welding groove to hold the parts together and apply tension to them in an axial direction. At this point, the rotor was tipped over to a horizontal *(Cont. on page 526)*

Fig. 5 — Welding Joints in Rotor Disks and Blades

Reported by
Arthur E. Focke
National Trustee
Indianapolis, Ind.

Supercharger Buckets Mass Produced by Precision Casting

SOME TIME AGO, our War Department recognized that our airplane engines must have more power, especially at high altitudes. As is well known, part of this requirement was furnished by the turbo-supercharger — a device consisting essentially of two parts: *(a)* A turbine driven by the exhaust gas from the engine, and *(b)* a centrifugal air compressor driven by the turbine. The compressed air, led to the carburetor, and thence to the cylinders, furnishes them as much oxygen as they would get if operating at sea-level, even in the rarefied air of extremely high altitudes, and thus maintains the engine efficiency and power output.

Within this turbo-supercharger the most critical part — the turbine blades, or "buckets" — would be subject to high stress from the rotational speed, which was to exceed 20,000 r.p.m., and at the same time they would be required to operate at temperatures up to 1600° F. in the direct stream of incandescent exhaust gases containing bromides, lead salts and sulphur compounds. Even though these individual buckets are rather small — typical ones shown in Fig. 1 being about ½ in. wide by 1¾ in. long — they are obviously machine parts which must be engineered with the greatest care.

It was known that certain of the cobalt-chromium-tungsten alloys known as Haynes Stellite — especially as modified by replacing the tungsten with an appropriate amount of molybdenum — would meet these service requirements, but this alloy was difficult to forge and machine, and buckets by the millions were required.

To meet this emergency, Haynes Stellite Co., of Kokomo, Ind., a unit of Union Carbide and Carbon Corp., late in 1941 put into mass production a molding and casting process developed by Austenal Laboratories, Inc., and Carbide and

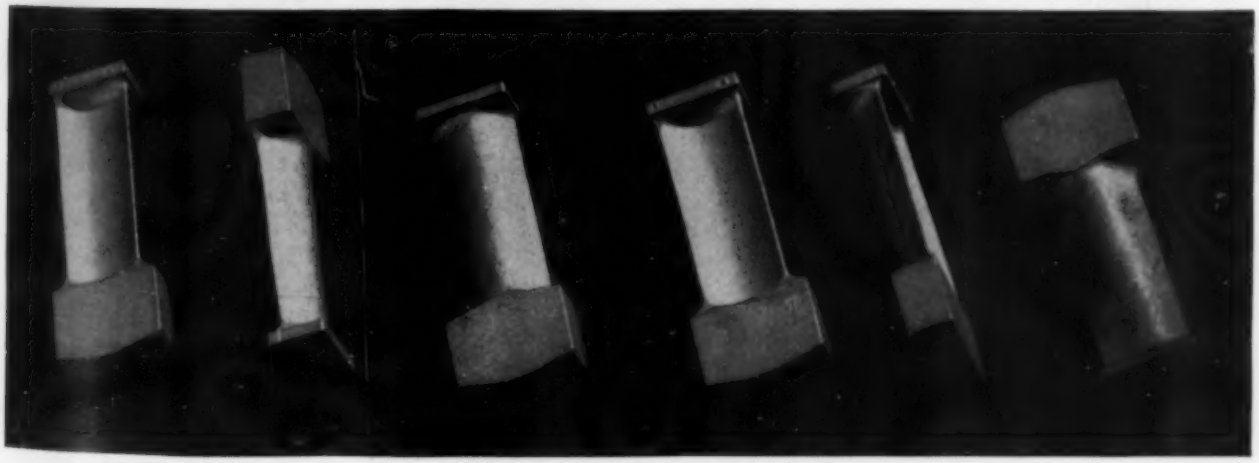


Fig. 1 — Several Views of a Typical Aircraft Supercharger Bucket, Produced by the Million by Precision Casting Methods

Carbon Chemicals Corp. This practice, using the so-called lost wax process long employed for casting dentures and metal appliances for bone surgery, provided the means of obtaining buckets of this alloy in the desired shape, and close enough to size so that final grinding could be more a means of touching up rather than a sizing operation involving actual stock removal.

Haynes Stellite Co., in addition to supplying all the alloy used for the entire production of these parts, has cast over 25,000,000 buckets. This represents the major portion of the total requirements of the turbo-supercharger manufacturers and the Air Corps. Production reached a peak monthly output of 2,100,000.

To make this contribution, it was necessary for the staff at Kokomo to develop many new practices. This article is an effort to show what could be seen if it were possible to make an inspection trip through this plant. Such trips are impossible at this time because such a high percentage of the production is still on items classified as confidential or restricted by the procuring agencies.

Making the Wax Pattern

The first step in the process of precision casting is the making of a master pattern from which a soft-metal die (Fig. 2) is fabricated for the injection molding of the accurate wax patterns. The die is similar to the core box of ordinary foundry practice, and is made of a tin-bismuth alloy to take advantage of its freedom from contraction in freezing. Like type metal it holds sharp impressions. The die itself is enclosed in a steel case to keep the soft alloy from flowing under the injection pressure.

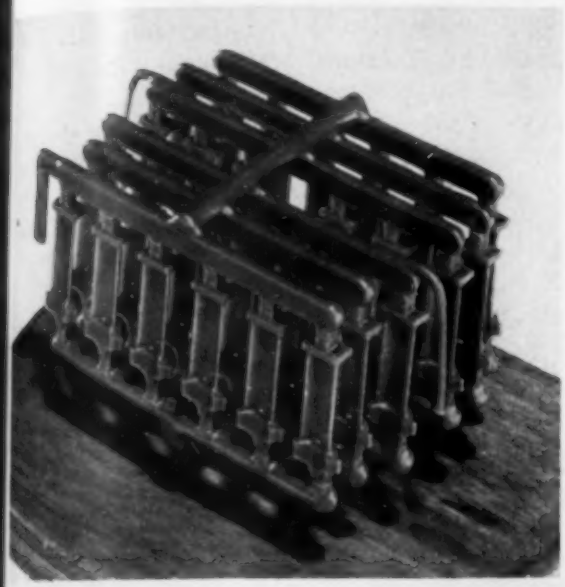
In the second step, a special wax (with hardening and toughening agents added to provide the required characteristics) is injected into the die. The molten wax, on which the temperature must be controlled to within 5° F. in order to obtain the necessary uniformity, is injected with a pressure gun into the die, as shown in Fig. 3, under a pressure of about 400 psi. When the die is opened, special knock-out pins are operated to free the wax pattern, which is then removed by hand. After this the die is sprayed with a soap solution to prevent sticking and is ready for another injection.

This pattern unit for six blades must then be assembled with five others to make a square nest for a single investment. Assembly to gate and feeder patterns, cast similarly in their own dies, is made with the aid of a "hot-wire welder"

Fig. 3 (Above) — The Closed Die (Center Foreground) Is Clamped in a Vise, a Gun Loaded With Molten Wax Placed Over the Gate, and Wax Forced in at About 400 Psi. The wax solidifies quickly, the mold is opened and the wax pattern removed and placed in a box (right foreground)

Fig. 2 — Die, in Open Position, for Six Buckets and Runners. Die is sprayed with soap solution, closed, and filled with wax

Fig. 4 — Complete Wax Panel for 36 Buckets, Mounted on a Mold Board



— simply a short piece of resistance wire heated by an electric current to a mild temperature that will melt the wax. The complete wax panel mounted on a mold board is shown in Fig. 4.

After a careful inspection of the finished panel, it is coated or dusted by holding it under a shower of the powdered facing material as it sifts through a vibrating screen. This assures a uniform surface on the finished part.

During these steps, a paper-lined mold case has been prepared, which is lowered over the panel mounted on a mold board (Fig. 5), and the junction of the mold and board is sealed by spreading hot wax over the outside of the joint with a narrow paint brush. The "pattern" (panel) and "flask" (mold board and case) are now ready for the "molding sand" (investment mix).

Fig. 5 — A Mold Case Has Been Lined With a Longer Paper Sleeve and Is Now Being Placed Over the Wax Pattern on Its Mold Board

The investment mix — a thick slurry of silica, magnesia, and brick dust in a water solution containing ethyl silicate, ethanol, hydrochloric acid and other chemicals — is prepared in an overhead room where the ingredients are accurately measured and thoroughly mixed in tumblers and barrels similar to barrel plating or tumbling equipment. From here it is dumped down a chute into a long shallow pan alongside the molding line, where workmen dip it into the mold cases — a hand operation.

Because this investment sets quickly, the flow of mold cases and investment material must be carefully coordinated. Equipment must also be cleaned frequently to prevent partially set-up lumps from being added to the mold. Naturally the investment must, at this point, conform itself *accurately* to the surface of the wax mold.

During filling, which is done under an efficient exhaust hood, each mold board rests on an inclined table, which slowly rotates, thus giving the wet and plastic mass ample opportunity to settle into the mold without trapping any air bubbles. The paper collar inside the mold case acts as a dam to hold the required amount of fluid investment without spilling, even in this inclined position.

Filled molds are then transferred to a vibrating table, where they rest flat on the mold board. The vibration settles some of the solids in the investment against the wax pattern so that the liquid phase can be jelled. After such vibrating, the mold is aged for about one hour, after which the excess paper feeder or collar can be trimmed away, the mold board knocked off and the green mold placed alongside others in a shallow tote box. A stack of these tote boxes is then trucked into the foundry.

Reaching the foundry the molds are placed side by side in a shallow horizontal oven with hinged top, which looks like a square sheet iron box, set about waist high. Temperature here is held just above the melting point of the wax. The molten wax drains out of the mold and much of it can be recovered, even though the aged investment is porous enough so that molten wax penetrates it to a depth of about one inch.

After dewaxing, the molds are placed on pallets made of heat resisting alloy and pushed

through a furnace such as shown in Fig. 6. Temperature in this furnace is regulated from fairly low to quite high; in the first chamber the remaining wax is burned out, the molds are then baked and finally fired to a temperature of about 1900° F. at the exit end. Molds are now ready for the casting floor.

First step in the foundry operations is to prepare a master heat of metal of the proper composition. This is done by charging the carefully weighed ingredients (mostly in the form of metal granules) into an electric furnace, melting them under controlled conditions, and then "pigging" the metal into long round rods by pouring from a hand ladle into permanent molds. Each heat is accurately analyzed and the rods from each heat properly segregated from other heats until they are consumed in the operations now to be described.

Rods are remelted in relatively tiny electric furnaces, illustrated in Fig. 7 — just enough metal at one time for a single mold. Rods are charged into the furnace through the discharge hole as shown in Fig. 7. After melting down and bringing the alloy to pouring temperature, an asbestos gasket is placed around the discharge hole of the furnace, a heated mold is taken from the exit end of the firing furnace and inverted over the pressure furnace (Fig. 8).

After the hot mold is clamped in place, the assembly is rocked to and fro several times and then inverted so the liquid metal runs from the furnace into the mold. At the same time 3-lb. air pressure is admitted to the furnace through a cock in the casing.

The entire operation of bringing up the hot mold, clamping it in place, and pouring requires no more than a few seconds.

When the casting has solidified, the clamp is loosened, the mold removed from the furnace and delivered to the cleaning room on a gravity chute. The furnace is then righted and another charge loaded.

As soon as the mold is cool, the investment is broken away from the casting under a pneumatic plunger, and the casting vibrated to loosen and remove the friable investment material between the nested buckets.

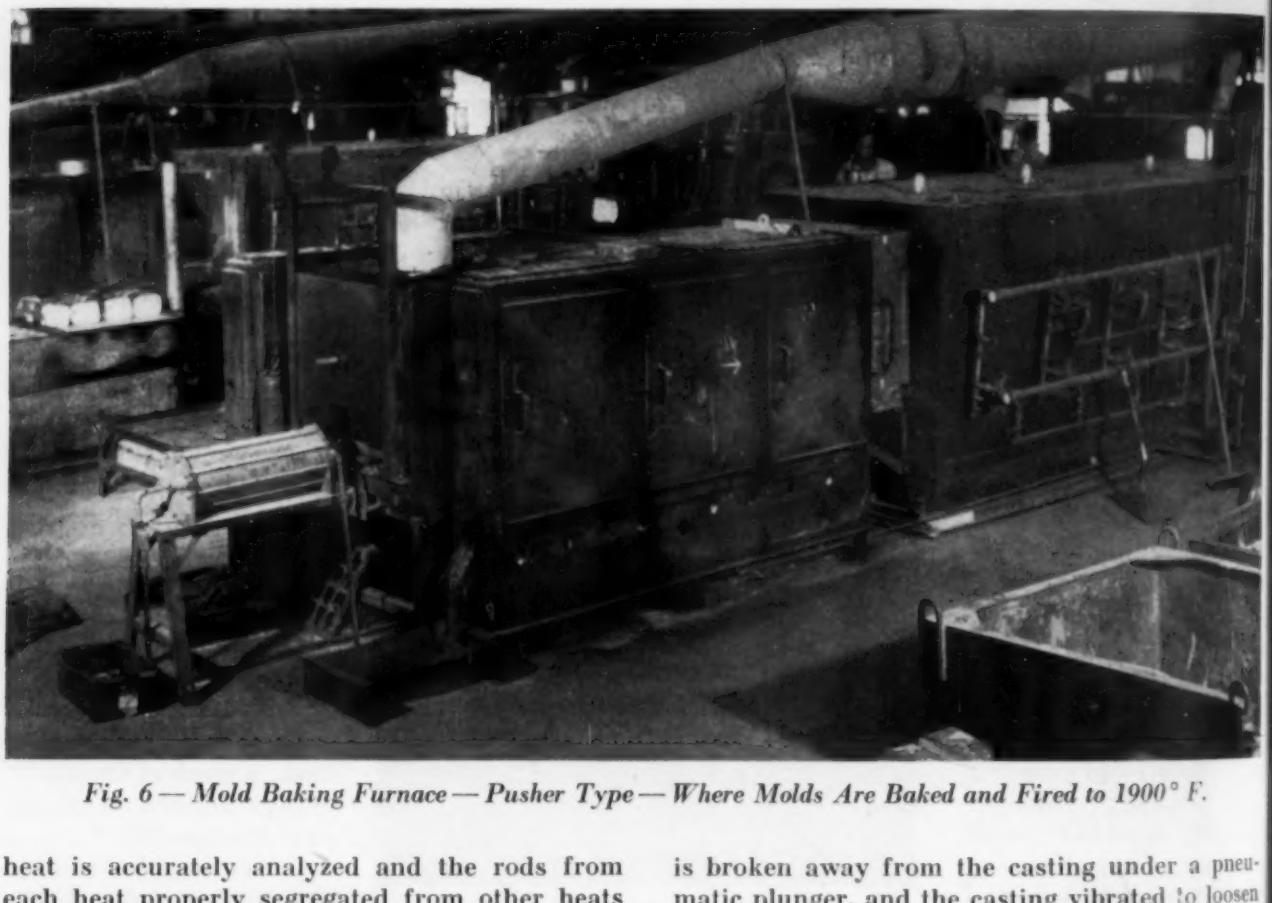


Fig. 6 — Mold Baking Furnace — Pusher Type — Where Molds Are Baked and Fired to 1900° F.

The castings poured from each master heat of alloy constitute one lot and they are kept separate and identified. After rough inspection, the hardness coupons are cut off, ground smooth and tested. Bend tests for adequate ductility are made on the special extension provided on each panel for this purpose. These extensions for the bend and hardness tests may be observed on the wax panels in Fig. 4.

Gates and runners are cut off and the cast-

Fig. 7 — Small Arc Furnace for Melting Alloy for a Single Casting. Operator is charging a rod of the alloy into the closed furnace

Fig. 8 (Right) — Inverting a Hot Mold Over the Charge Hole in the Cover of the Electric Furnace

used for these buckets is 65,000 psi. at 1500° F.

While the description in this article has been based solely on the production of the turbo-supercharger buckets, Haynes Stellite Co. has applied this same process successfully in the production of scores of other parts, either in this same alloy, in their nickel-base "Hastelloy" alloys, or in many other special alloys. The new developments in turbine type motors for jet propulsion aircraft, which use buckets and blades under much the same conditions as those described for the turbo-supercharger, have apparently opened an enormous field for the application of this process. Some remarks as to its possibilities for other purposes in wartime and peacetime may therefore be in order.

Officials of Haynes Stellite Co. recognize that this process can also be applied to castings of lower alloy steels, but they feel that it is particularly suited for the production of intricate parts where higher and special alloys are necessary to meet the service requirements. Working with the War Depart-

ings sand blasted. The gating method used makes it necessary to grind the ends, using special jigs on a Blanchard grinder.

Various hand grinding operations are required to touch up local irregularities, after which the buckets are shot blasted and subjected to a final inspection. When the buckets have been found to be acceptable dimensionally, they are loaded into special compartmented boxes, X-rayed, and the film examined for evidence of defects in the castings (Fig. 11). After eliminating any defective buckets, the finished buckets are shipped in the same compartmented boxes used for the X-ray inspection.

Tensile test coupons are attached to some of the investment castings, and these are tested at high temperature in more or less conventional equipment. The average short-time tensile strength of the special high alloy

Fig. 9 — Furnace and Mold Tilted so Metal Runs Into Mold. Operator turns on 3-lb. air pressure

Fig. 10 — Cutting Buckets Apart With High Speed Abrasive Wheel

ment they are devoting extensive research to the application of this precision casting process to new parts of many different designs, and one division has been set aside as a pilot plant to work out the details for mass production of these items.

When a new item is submitted for production it is necessary to add two more steps to those outlined above for the turbo-supercharger buckets. First, it is necessary to consider whether or not there is a reasonable probability that the item can be produced satisfactorily by this process. In addition to considering such factors as materials and quantities, it is necessary to study the size and shape of the item and the dimensional tolerances. For parts which must be pressure cast, 5 lb. is the maximum capacity of the standard furnaces at Kokomo, with 3½ lb. representing the charge for an average investment casting or group. The minimum size is determined by the gate and runner size; parts that weigh as little as ½ oz. have been made in quantities. (Some small or large parts for high temperature devices do not need to be cast by the pressure method and are, therefore, not included in these weight limitations.)

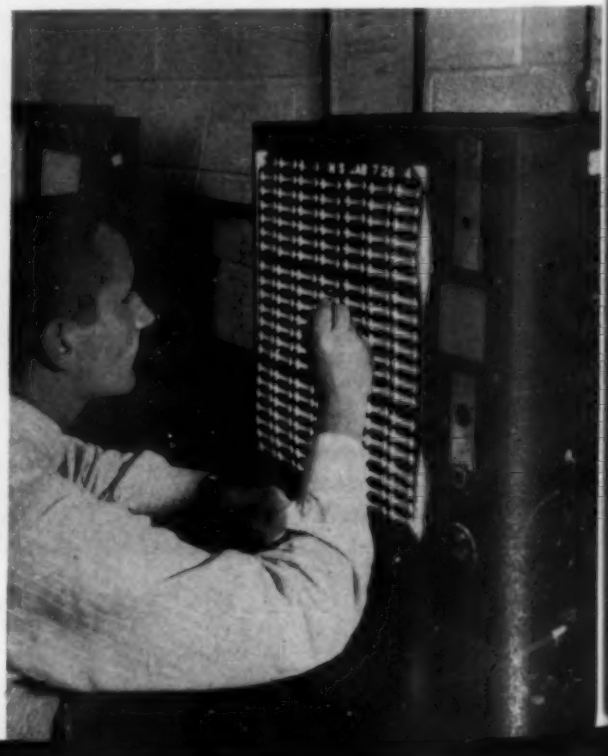
Whether or not very thin parts can be cast successfully depends upon the shape and overall design of the part. Blades 1 in. wide and up to 6 in. long have been cast successfully, in large quantity production, as thin as 0.015 in. at the outer edge. Even though it is possible to hold critical dimensions on experimental jobs to ±0.002 in. in ½-in. sections, combinations of variables encountered in production require greater tolerances if a large proportion of rejections are to be avoided.

While the gate, feeder, runner and general die design can be worked out to hold one dimension very closely, the purchaser cannot expect that similar close tolerances can be held on *all* the other dimensions. Cast parts are often ground to hold a critical dimension, as has been described in grinding the gated area of the buckets.

If it is concluded, after study, that the item does not include any factors which would make its production by this process impracticable, a master pattern of the part is prepared of brass, steel or stellite, on which all the dimensions are increased about 1.5% to allow for shrinkage of the casting in solidifying and cooling. When the first die is made from the master pattern, the initial wax pattern is injected in it, removed, and mounted with the necessary wax runners, gates and feeders. Finally, trial molds and castings are made from these test wax panels which may be altered as required to make successful parts. When a successful wax panel design has been established, permanent dies are prepared and production proceeds as described above for the turbo-supercharger buckets.

From all this, it is clear that a vast amount of technical knowledge and skill is necessary to work out the complicated problems involved in producing new items at the rate that has been set by the armed forces, and it is impossible to overestimate the value of the contribution the executives, staff members and production employees of the Haynes Stellite Co. have made in this respect.

Fig. 11 — Examining the Radiograph of a Tray-Load of Buckets to Determine Possible Internal Unsoundness; a 100% Test



Critical Points

By the Editor

CONVINCED that nearly everything that follows in the next three pages — indeed much that has been planned in all activities of human life — must be re-examined in the blinding light from the atomic bomb, if in fact it is of any value whatsoever. So turned back more or less aimlessly through *Metal Progress* until something was found in Critical Points for January 1942 that still stands four-square: "Gradually convinced that the Japs' assault on Pearl Harbor while their ambassador and special envoy were actually talking peace will turn out to be the dumbest act of the lunatic decade."....And then, going a little further back, found a forgotten item (June 1940) entitled "Uranium, the End Element — or the Beginning of the End (?)". It was a comment by MARTIN SEYT on some writings of KARL K. DARROW about "Nuclear Fission" in *Bell System Technical Journal*. Dr. DARROW noted that heretofore all atomic bombardments had resulted, if in anything, in minor fragments whose energy was absorbed rapidly by their neighboring atoms with no bad after-effects. However, real atom smashing occurred when uranium 235 was hit by a slow moving neutron — an uncharged particle and hence uncontrollable by electrical or magnetic fields. The uranium split into two heavy fragments and a wholly unprecedented shower of particles (including a lot more neutrons) and a portion of the atom's original mass disappeared in the form of tremendous energy. Dr. DARROW continues: "Must we not then anticipate a self-sustaining, nay even a self-amplifying effect? Must we not fear, in fact, a cataclysmic explosion? Were anything of the sort to happen, we may take it for granted that the world would know of it, though in all probability the experimenter would not himself survive to report it. Evidently then it has not happened, and there must be a brake or brakes in Nature which impede the slide toward the catastrophe, and have thus far averted it. In other words, there must be ways in which the evolved neutrons are made harmless by some innocuous type of capture, before they ever produce a fission." MARTIN SEYT wrote that seemingly the danger would be acute if uranium 235 were to be accumulated in considerable quantity and visited by an aimless neutron. Dr. DARROW replies with the rather slender hope "that those who build up great masses of sensitive uranium will recognize preliminary signs that the danger-point is close, before they actually attain it." What bothered MARTIN SEYT at that time bothers the Editor just now. If a thimbleful of uranium 235 can explode with the energy of a billion thunderbolts, other elements also will be found vulnerable. Even the stable ones may be made unstable and the world's lives and liberties held at the mercy of some future pint-sized Hitler possessing that knowledge and resources to gather the stuff. MARTIN SEYT five years ago was also "vaguely fearful that some day some rash physicist will touch off a snowball reaction that will announce itself to Christendom in an all-consuming, all-shattering eruption, instantaneously reducing the entire planet to star dust, an event noted some thousands of years later by astronomers on the nearest inhabited sphere as a novum rapidly attaining great brilliance but as rapidly fading."....On that item the Editor also stands, firmly believing.

Uranium 235

IT IS SAID that a friend congratulated General KNUDSEN on his return to civilian life, saying that it must be fine to get back into big business, forgetful that the biggest business in the world, figuratively, was the war and the biggest business in the world, literally, is our aircraft industry. Its 1944 production was worth 20 billion dollars, five times the largest annual output of the entire American automotive industry which Knudsen left and presumably is returning to. The friend should spend some days at Wright Field in Dayton, Ohio, and get some inkling of the size, complexity and seriousness of this business of waging air war. Wright Field is a sort of centralized testing laboratory; it is undoubtedly the biggest technical institution in the world — even so, it contains only a part of the current

World's largest research laboratory

study and development of air frames, engines and flying accessories. For example, a single manufacturer has, at Caldwell in New Jersey, a group of men and scientific installations studying nothing but propeller blades and accessories that is matched by few prewar research organizations. Multiply this by a hundred, and then on top of it all place Wright Field at Dayton, where about 8300 people are working in the Engineering Division of the Air Technical Service Command alone, with equipment and offices housed in building after building until the imagination is lost — even then the observer will be astonished at the individual achievements parading before his eyes.

GENERAL CARROLL, head of the engineering division at Wright Field, 8300 strong, emphasizes that the *materials* of aircraft construction are all-important, especially in recent years where large demands and war embargoes have caused great shortages in many critical items. The most difficult of the substitutional problems, however, are in rubber, silk, lubricants and other non-metallics; the rule adopted by the airmen is that the substitute must be at least as good as the thing originally specified. With due regard to the importance of materials, it appears to an outsider that *design* is equally necessary. Else how, for example, could an electrical generator, which in 1936 weighed 31 lb. and developed 0.6 kva., be converted into the present generator developing 5.7 kva. and weighing only 46 lb.? External dimensions are the same and cost has only doubled ($85 to $165). This 10 to 1 improvement without weight penalty is "a clear case of getting something for nothing" in Col. HOLLIDAY's words (chief of the section) — nothing, he might have added, but a lot of brains and work.....While a majority of the Air Technical Service Command's activities at Wright Field are in line of testing new designs by aircraft manufacturers and their sub-contractors, already worked out by an infinitude of study and investigation at other localities, some of the most fascinating work in Dayton has to do with the reactions of the human body and mind to extreme conditions of flight. This is a non-metallurgical matter, but the metallurgist immediately asks, "What is the reproducibility of such tests? Is the scatter of results — such results as can be evaluated in figures — great or small?" The answer is that the *individual* is remarkably constant in his reactions: If he tests 100 in a certain experiment today, he will not vary more than 5% either way on retesting at a later date. However, there is a much larger variation, man to man. For example, in the "human centrifuge" — a scientific merry-go-round simulating the action of a fast flying plane making a sharp inside turn, or pulling out of a tremendous power dive — a man goes temporarily blind when the blood is pressed from his head and eyes toward his feet by the centrifugal force. This "black-out" is, on the average, at accelerations close to six times the value of gravity; under these conditions a 160-lb. man weighs half-a-ton, and the strongest of them can hardly lift his heavy arm above his head. However, certain individuals may black out as low as 2½ g., whereas rare ones are found that maintain their faculties for 10 sec. at 8 g. Obviously, the latter are the boys for the fast fighters, if they are otherwise competent.....Throughout the laboratories and work shops the visitor is impressed by their orderliness. Each unit is built for a particular purpose and is in use for that purpose. There are no makeshifts, no debris from studies completed or abandoned, no instruments gathering soot or dust. Since the main object is to test aircraft components it is only natural that special chambers abound, large and small, where every condition of temperature, humidity, pressure, and velocity up to supersonic speeds can be created in any combination and in any rate of change. All the while the item being tested (whether it is a simple static part, a moving mechanism, a gun or a human being) is under close observation by all sorts of recording instruments.....A trip down the flight line indicates that the prime interest by airmen now is in *big* things. The fighters now are as big as the old bombers, the bombers are bigger than the biggest of the old transports, the transports of tomorrow are flying boxcars. Even the biggest of the wind tunnels can take only minor components of these leviathans; static tests on completed aircraft, simulating predicted flying loads, occupy hangars as big as the concourse in Grand Central's railway station. In this respect, General CARROLL said that the first B-17 was the most important airplane ever built. It was entirely too big to bring inside the laboratories they had at that time, so they put all sorts of instruments into it and made a flying laboratory out of it, thus ushering in a whole new art of flight testing. The men at the top always took the attitude of being unsatisfied with the B-17's performance, and consequently this ship has been vastly improved. Thus, while its gross weight has increased from 34,500 to 64,000 lb., its overall dimensions are unchanged, its horsepower has been increased from 3200 to 4500.

How much can a man (or a machine part) endure?

Trend toward huge aircraft

its speed from 220 to 330 miles per hour, and its useful load at maximum range from 10,000 to 30,000 lb. This represents the normal course of development: A good ship is made and put into production; it is intently studied and improved in numerous respects; eventually it seems to reach its ceiling of performance; by then another good ship is ready, at the start of its career, to take on where the other leaves off..... All in all, the observer sees numberless new things at Wright Field, all pointed toward larger, more powerful military cargo planes, better protection of carrier borne troops, more adequate flying instruments for all-weather flying. It therefore becomes obvious that the Air Technical Service Command started years ago on the task of converting the logistics of the Pacific war, with its great distances, into one of rapid transit for men and material by air.

SHOWN BY KENNETH CAMPBELL, works metallurgist of Armco's plant (Sheffield Steel of Texas) near Houston, through the special department for forging blanks for 155-mm. high explosive shell —150,000 every month. Billets of 1050 steel, 6⅜ in. square, are cut into 22-in. lengths by a gang cutter with five torches. These double-lengths are then broken in half by a hydraulic press at shallow notches previously flame-cut; the fractured surface permits 100% inspection for pipe. One might think that *both* ends could be a nick-and-break, but when they are cut by flame into doubles it guarantees that no blanks will be badly over-size or under-size on account of irregular fractures, and the flame-cut surface gives a square base on which to ride upright through the heating furnace. The fractured end forms the base of the shell-forging, and being inspected for soundness is extra protection against penetration by flame from the propellant at the instant of firing. .....Two production lines operate. Billets are heated to 2350° F. in a Salem rotary-hearth forging furnace, of which a traveler now sees many. New to me was the charging and discharging equipment, consisting of a water-cooled arm, 25 ft. long, with air-operated fingers on the furnace end, and handles and valves on the other. The arm is hung midlength from an overhead trolley and the support includes an air cylinder for tilting the arm like a seesaw. By push buttons and valve levers the operator runs the arm into the furnace, lifts the hot billet off the hearth, draws it out the door and drops it in on a conveyer just outside.....Enroute to the forge the billet goes through a short tunnel where it is de-scaled by a shot of 1500-lb. water — "shot" is the right word, for when the spray hits the hot steel it sounds like a hand grenade had exploded. .....Forging is a three-operation job; the square billet is partly pierced and expanded into a shallow round cup or "bottle", 8¼ in. diameter, with proper thickness and contour of base, in one stroke of a 500-ton Clearing press. (Two presses are provided in each line.) The walls or skirts are then rolled back over a mandrel in a Witter mill (three rolls set slightly at an angle and operating like a piercing mill), and finally the hot piece, mandrel still enclosed, is pushed through a sizing die, coming out in a blank 6⅜ in. outside diameter by 26 in. long. Thus the exact shape of the internal cavity is provided. These hot blanks are then put through a long muffle, taking 2 hr. for cooling down to 700° F., then water cooled, shot blasted inside, and given "125% inspection" in CAMPBELL's words. The girls pay most attention to the size and surface of the internal cavity, for this gets no further shaping or machining. Hardness is limited to 243 Brinell for machinability; average hardness after the controlled cooling is about 200.

Forging 155-mm. H.E. shell

TO FREEPORT, near Galveston, where Dow Chemical Co. is "mining" an ore containing 0.13% magnesium — sea water from the Gulf of Mexico. Of course, the bulk of the equipment is devoted to concentrating this lean ore into a rich feed for the electrolytic cell from which magnesium metal finally is taken. Briefly these preliminaries add milk of lime (made from oyster shells dredged nearby) in a precise excess (to prevent the 5 parts boron per million in the sea water from coming out also, and fouling up the electrolysis) and in a precise way (so the magnesium hydrate will flocculate, settle and filter). This filtered hydrate contains much sea water, with its natural salt and some calcium chloride from the excess of lime reagent and these salts must be removed from the hydrate without too much wash water, filtering and other trouble. So the magnesium hydrate is converted back to chloride by adding HCl; then some H_2SO_4 precipitates the calcium. That eliminates the first major impurity that has come along as chloride. Next, the job is to separate the magnesium and the sodium chloride. When the weak solution is evaporated to 35% by spraying it into a current of hot air the common salt (NaCl) crystallizes out. The settled solution — now fairly pure magnesium chloride — is then boiled to about 48% $MgCl_2$ (nearly to the point where it starts to solidify as $MgCl_2 \cdot 2H_2O$) and

Magnesium (and gold?) from the sea

from here it is converted to round granules containing 75% $MgCl_2$ by hot air as it passes through a shelf dryer designed much like a Herreshoff roasting furnace. It is at last ready for electrolysis.....The "pot" or "bath tub" in which the chloride is electrolyzed is intriguing in its inner complexity. The steel pot itself is the cathode; 22 round graphite anodes project downward through the arched brick roof. The electrolyte is a mixture of chlorides, heavier than magnesium metal, and it might be expected therefore that the current would short circuit immediately, from graphite electrodes to steel cell-wall, through a floating layer of magnesium — and indeed it would if the metal were in a continuous blanket. However, the bath is in vigorous agitation, not only from heat convection and electromotive forces but it is also churned up by steam and chlorine gas evolved from the reduction. This keeps the metal broken up into globules, small enough and separate enough to prevent anything more than a momentary short circuit. By a complicated set of internal steel deflectors, this magnesium is led away from the graphite anodes into a side channel leading to a collecting basin at one end of the pot. The chlorine evolved is collected, converted into hydrochloric acid and put back into the process to change new $Mg(OH)_2$ into $MgCl_2$.....The magnesium division at Freeport, even though it makes 36,000,000 lb. of metal per year, is a relatively small consumer of sea water. Dow's major job here is to extract bromine from sea water and its manufacture into ethylene dibromide for high octane gasoline. This is a non-metallurgical operation, but attracts the metallurgist's eye because very little down here in semi-tropical Texas is housed except electrical equipment, control equipment, and the magnesium cells. The chemical processes go forward in vast accumulations of pipes, tanks, vessels, pumps and valves. WILLIAM SCHAMBRA, our guide, assured us that in one gargantuan plumber's nightmare he called "the styrene plant" there are about 1000 control instruments, so we were tempted to speculate whether there might not be a few master control instruments to control the control instruments. .....Corrosion is a very serious problem. External corrosion by salty seashore atmosphere is fought by a gang of painters — everything that meets the eye has its own brilliant color, as though painted but yesterday. Internal corrosion of steel conduits, pipes and tanks by sea water is controlled by immersing magnesium metal slabs (anodes) at about 20-ft. intervals so the iron is protected by sacrificial action. Gunite cement is also good against sea water. Hot magnesium chloride solutions require stainless steel; 18-8 with either molybdenum or columbium has been very successful for containers where stresses are kept low enough to avoid stress corrosion..... Since bromine, existing in the sea water to the extent of 67 parts per million, is successfully extracted, one speculates whether gold could not be recovered from the same source. It is said, perhaps truly, that the ocean is the world's biggest gold mine; however it is an exceedingly lean one, carrying only about 0.006 parts per *billion*. Suppose *all* of this were extracted from *all* the 250,000 gal. of sea water pumped through this plant every minute, the annual take would come to 100 troy oz. or $3500 worth. Hardly worth the trouble!.....Coming back to the problem of making gold from magnesium, many have speculated about the future use of the overgrown American industry. Prior to the war (1941), Dow Chemical Co., the American pioneer, had capacity for 12,000,000 lb. of metal per year, but could sell only 4,500,000 lb. to customers in this country. This Freeport plant alone now can make 36,000,000 lb., but this in turn is only a small part of our war-time capacity (600,000,000 lb. per year, 85% owned by Uncle Sam). Most of this is idle now*; we can't even use all of it in our own war industries. What are the peace-time prospects? An admittedly optimistic and long-shot estimate for annual requirements as of 1950 was published in February in *Technology Review* by ARTHUR LOWERY, on the basis of information derived during his service with the War Production Board. His Yankee guess:

Protecting steel from salt water

Want some magnesium?

Air transportation	11,000,000 lb.
Land transportation	5,000,000
Water transportation	500,000
Portable tools	2,500,000
Industrial machinery	10,000,000
Consumers' goods	5,000,000
Alloying with aluminum	7,500,000
Chemical industry	10,000,000
Total as of 1950	51,500,000 lb. per year

*Our highest production rate of 500,000,000 lb. of new magnesium per year was achieved for the first quarter of 1944; our highest production in any 12 months was between May 1943 and May of 1944: 435,000,000 lb.

Izod of London — Flannels With an Air

A handsome pedigreed look to them... these thoroughbred flannels designed by the British wizard of tailoring, executed here in America for the casual life. Exclusive with Jay Thorpe in New York.

(Advertising often shakes your belief in things!)

By Conrad C. Wissmann
SF 3/C
Construction Battalion
U. S. Navy

Deoxidizing a Heat of Acid Electric Steel

PREVIOUS ISSUES of *Metal Progress* (October and December 1944) contained a brief account of acid electric steelmaking practice and a somewhat detailed discussion of the method of working a heat. After this lapse of months, the proposed series of articles will be continued — written, it is hoped, in a way that will be informative to the melters and helpers. This one on the deoxidation process will be followed by another on the chemistry of the steel itself, and the task will be finished with a somewhat detailed discussion of slags.

In making a heat of steel it is the melter's job to adjust the alloy content of the steel to a certain analysis and also to have the steel, when it is tapped from the furnace, in as clean a condition as possible. The various amounts of the different alloys which are necessary to add to the steel to give a certain analysis in the finished steel will be discussed in a later article. This one will confine itself to the means a melter has of cleaning the steel of the impurities which are in it before it is tapped.

A clean steel is one which is as free as possible of inclusions — admittedly not a precise definition, but the matter is yet to be standardized. By inclusions are meant the oxidation products of iron, manganese, silicon and aluminum, the reactions by which they are formed being as follows:

$$Fe + O \rightarrow FeO$$
$$Mn + O \rightarrow MnO$$
$$Si + 2O \rightarrow SiO_2$$
$$2Al + 3O \rightarrow Al_2O_3$$

These oxides, FeO, MnO, SiO_2, Al_2O_3, and combinations thereof, make up the inclusions found commonly in steel. As can be seen from the equations, if it were possible to tap a heat of steel with absolutely no oxygen in it there could be no inclusions in the steel. (In this discussion I exclude from "inclusions" the particles of refractory, molding sand or wash that sometimes get into the casting. Inclusions have been likened to dirt, since they are various metallic oxides and earth itself is primarily composed of different metallic oxides.)

As can be readily guessed, the presence of these non-metallic particles has a weakening effect on the metal. Therefore, it is safe to assume that the greater the number of these particles, the weaker the steel. However, even more important than their number and amount seems to be the *shape* of the inclusions and their location in the steel's crystalline structure.

For example, a sample of steel as viewed under the microscope may have quite a few large rounded inclusions in it and still the steel will have good physical properties. Another sample of steel will look fairly clean under the microscope but the inclusions will be of a stringy nature and they are found at the grain boundaries. This steel will have very poor physical properties.

Now, the type and the amount of inclusions found in any steel result from the melting practice under which the steel was made. Therefore, the production of a clean steel is a problem for the steelmaker. Since inclusions or oxides in the metal are assumed to be harmful, let us study the various agents which can be added to steel to combine with the oxygen and remove it from the metallic bath.

Shot aluminum or manganese and silicon (usually in the form of ferro-alloys) are the deoxidizers commonly used in steelmaking. Their relative "strength" is shown by the lines in Fig. 6. By the strength of a deoxidizer is meant the ability which that deoxidizer has for combining with the oxygen in the steel. One very

good measure of this ability is to determine what per cent of oxygen will remain in the bath combined with iron even though a certain amount of the deoxidizer also is present. This is shown for the three common deoxidizers in Fig. 6. For example, manganese will readily combine with oxygen, forming manganese oxide. However, after all of the manganese has reacted that can possibly react, there is still considerable oxygen left in the steel uncombined as FeO. As a specific instance, suppose the steel bath is at 3100° F. (about 1700° C.) and we have added enough ferromanganese so that the steel analyzes 0.75% manganese, there would still be 0.137% FeO dissolved in the bath. This is shown at point *A*.

Silicon is a considerably stronger deoxidizer than manganese, as is apparent from the graph. Note conditions as at point *B*: Bath at 3100° F. (1700° C.), steel analyzing 0.40% silicon, only about 0.05% FeO dissolved in the bath. If only 0.40% manganese had been added, point *C* would show that nearly 0.20% FeO would remain. At 3100° F., therefore, silicon may be thought of as having four times the strength of manganese. (Note that the diagram is drawn with logarithmic coordinates, that is, the scale is proportionately expanded as the quantities get lower and lower.)

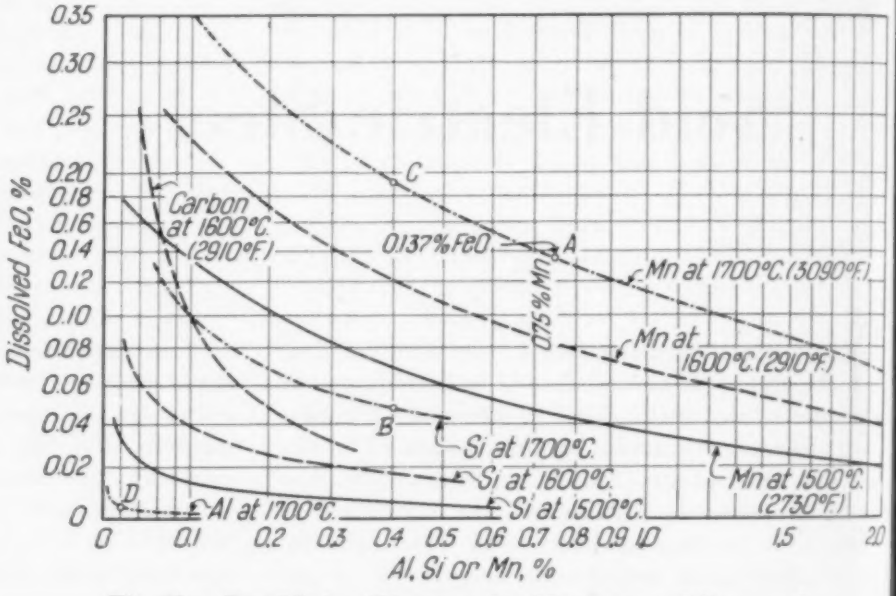


Fig. 6★ — Deoxidation Diagrams for Manganese, Silicon and Aluminum at Steelmaking Temperatures (Chipman). The carbon line is transferred from Fig. 5 in the previous installment

If it were not for the expanded scale of coordinates at low amounts, aluminum could hardly be shown except as a dot near the zero corner. As it is, it is obvious that aluminum is a very good deoxidizer. If enough is added to steel at 3100° F. to leave only 0.02% behind as aluminum, the FeO will be down to 0.005% (point *D*).

There is no room on the chart for the curves for aluminum at 2910 and 2730° F. They are below and to the left of the one shown. At 2730° F. (1500° C.), for example, 0.01% aluminum is in equilibrium with a little less than 0.0005% FeO in the steel.

It should be remembered that the percentage of the alloys shown in Fig. 6 refers to the amount remaining in the steel uncombined, and *not* to the amount added. When we say that silicon is four times as strong a deoxidizer as manganese it does not mean that only one-quarter as much silicon as manganese would have to be added to steel to deoxidize it. It merely means that if enough silicon has been added so that a residual of silicon or manganese or aluminum is left in the steel uncombined in the amounts graphed on the chart, the FeO left dissolved in the steel will correspond to the amount shown by the coordinates at the left of the respective curves.

No chemical reaction ever goes to completion. For example, we can write an equation stating $Si + 2FeO = SiO_2 + 2Fe$, or we can also write the reverse: $2Fe + SiO_2 = Si + 2FeO$, and both would be correct, since each may take place, depending on the respective amounts present and the temperature. When we speak of the "strength" of deoxidizers we mean that the stronger the deoxidizer, the greater tendency it has to remove oxygen from any FeO there may be around, and the less the tendency the FeO has to reduce the oxide which the deoxidizer forms.

If three samples of steel are taken from a heat and to each sample is added enough of one of the three deoxidizers to combine with the entire amount of FeO in each sample, after the reaction the manganese-killed sample will have the greatest amount of FeO left in the metal, or, putting it another way, the greatest amount of oxygen uncombined with the manganese. The

★The figure numbers are consecutive with those in previous articles. This Fig. 6 is an assemblage of three diagrams given by John Chipman in his article "Application of Thermodynamics to the Deoxidation of Liquid Steel", in *Transactions* ⊕ for May, 1934.

silicon-killed sample will have less FeO left in the sample, and the aluminum-killed sample will leave by far the least FeO after the reaction has taken place.

Carbon also can be used and very effectively as a deoxidizing agent. As shown in Fig. 6 it is intermediate in power as a deoxidizer between manganese and silicon when the temperature is 2900° F. (1600° C.). However, its ability to combine with oxygen *increases* with temperature. In this it is different from the three others already discussed, which are in equilibrium with more and more FeO as the temperature rises. Also there is one distinct advantage of using carbon as a deoxidizer, and that is that the product of the deoxidation is a gas (carbon monoxide) which bubbles up out of the metal and is eliminated from the bath very quickly.

Carbon the Best Deoxidizer

It is the author's opinion that a melter should consider carbon the most useful of the four deoxidizers used in steelmaking, for this very reason, namely, it leaves no product of the reaction in the steel. The other three deoxidizers, aluminum, silicon and manganese, form oxidation products which are solid (or liquid) and therefore have a much higher specific gravity than carbon monoxide gas and will be much harder to remove from the bath. In the working of a heat the bulk of the deoxidation is actually accomplished by carbon during the boiling stage. After the boil, however, there is still considerable FeO left in the steel — especially if the carbon has been driven pretty low, and therefore the stronger deoxidizers, manganese and silicon, are added to lower the FeO content of the bath still further.

Ridding the steel of "inclusions" (oxidation products of SiO_2 and MnO) presents something of a problem, since immediately after their formation they are not in a condition or state to remove themselves from the metal. However, since these particles have a lower specific gravity than the metal, they will tend to rise to the surface of the bath and join the slag. This is what the steelmaker wants to happen. The *time* required for the particle to move upward through the bath and join the slag may be calculated by the formula called "Stokes's Law".

From this formula it can be deduced that the rapid rise of a particle is favored most by a large size, second by a low specific gravity, and third, by a low viscosity in the steel. Obviously, also, the time for an oxide particle to rise will depend on its depth in the bath, and the overall time for the deepest particle will depend on the total depth of metal in the furnace.

Let us discuss each one of these variables and see how we can control them to our advantage. We will start the explanation with the least important.

First, the low viscosity of the steel. It decreases as the temperature rises. Therefore, inclusions will rise out of the steel at a faster rate the higher the temperature of the metal, other things being equal.

Second, the low density of the particles. This variable cannot be controlled to any extent by the melter. However, it explains why the oxidation product of carbon, which is a gas with a very low density, rises out of the steel so quickly.

The most important variable is the size of the particle; in fact, the rate at which a particle will rise from the bath is proportional to the square of its radius. Particle size can be controlled to a very great extent by the melter, by two factors, namely, surface tension and fluidity. When a deoxidizer such as aluminum, silicon or manganese is added to steel, a cloud of fine particles is formed. The problem then is to make these particles coalesce to form larger droplets. If the deoxidation products are solid they will not stick together. However, if they are liquid they will join together when they come in contact to form a single particle with a larger diameter.

Consequently, the determining factor as to whether or not the particles will coalesce seems to be their melting point, since if they are liquid they will coalesce, if solid they will not. Therefore, it might be well to study the melting points of the various combinations of the products of deoxidation. Since, during the melting down and working of a heat of plain carbon steel there are only three important metallic oxides in the metal, the melting points of various combinations of these three compounds will be studied first, the compounds being FeO, MnO and SiO_2.

Figure 7 is a sketch of the equilibrium diagram of the binary system, FeO and SiO_2. "Binary system" means that only two substances

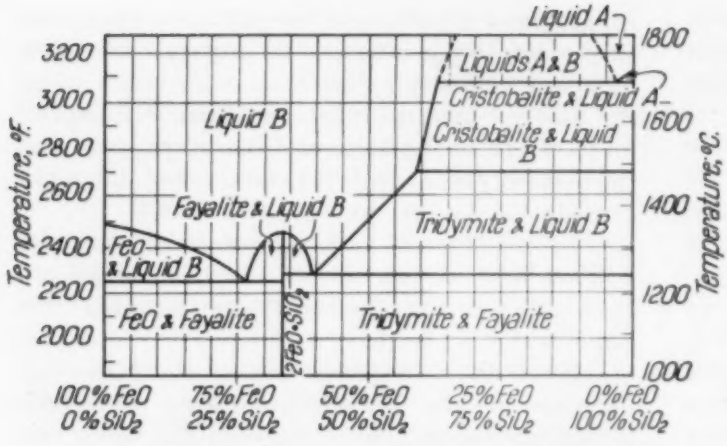


Fig. 7 — Equilibrium Diagram for Iron Silicate Slags

a and *b* are involved, and they may be present in any proportion from pure *a* through all mixtures up to pure *b*. (*a* in this case is iron oxide FeO, and *b* is silicon oxide SiO_2.) The equilibrium diagram is merely a map of such a system showing its condition at all temperatures up to the melting points. In Fig. 7 therefore the horizontal coordinates represent percentages of SiO_2 in FeO, and the vertical coordinates represent temperature. Our principal interest is in the upper line which is called the "liquidus" and maps the separation of liquid and solid or, more precisely, the temperature at which on slow cooling the first solid appears.

This map in Fig. 7 immediately shows us that these slags (particles made solely of iron and silicon oxides) are liquid at 2700° F. and higher if they contain less than 60% silica. Such iron silicate slags with up to 50% SiO_2 are very fluid, but the fluidity of any higher silica slag decreases rapidly as the silica content increases from this point. Generally speaking, therefore, it is necessary to have a high percentage of FeO in the metal if it is to be deoxidized with ferrosilicon; otherwise the slags will not be fluid and the deoxidation products will tend to remain in the bath. Result — a dirty steel.

In the system FeO-MnO, however, the fluidity of the system gradually increases as the FeO content of the system increases, as shown in the equilibrium diagram of Fig. 8. Here, again, the upper curved line is the liquidus, the boundary between completely liquid and partially solid, as it relates to composition and temperature. (The binary system, MnO and FeO, is entirely different from FeO and SiO_2, as is evident to the most casual inspection. There is a definite iron silicate mineral of definite chemical composition which forms from definite mixtures of FeO and SiO_2; this is shown as "fayalite" in Fig. 7. Iron and manganese are two metals of such close similarity, chemically and physically, that their oxides form "solid solutions" or amorphous glasses in all mixtures from pure FeO to pure MnO.)

The third binary pair possible in our system of three oxides is the system between MnO and SiO_2 (Fig. 9), and it is the most important from the standpoint of killed steel. Pure manganese oxide melts at about 2900° F. (1600° C.) and addition of any amount of SiO_2 up to 65% SiO_2 will result in a slag of lower melting point. The lowest melting point slags (about 2400° F.) occur between 30% MnO, 70% SiO_2 and 45% MnO, 55% SiO_2, and it will be seen therefore that if proper manganese silicates can be formed when the steel is killed, the slag particles will stay liquid until the steel itself solidifies, and thus have the best chance and

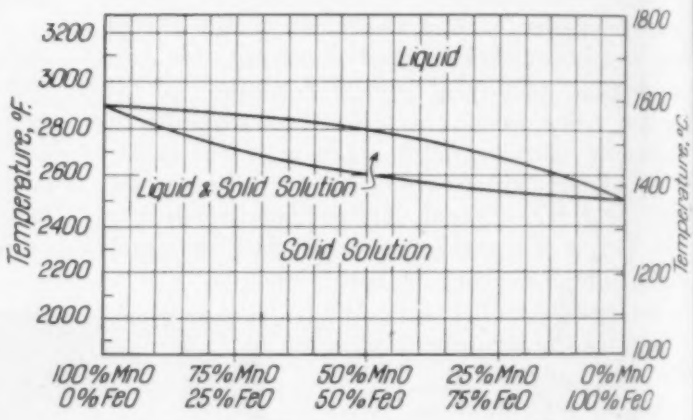


Fig. 8 — Equilibrium Diagram for MnO-FeO

longest time to coalesce and rise into the slag, or even from the casting into the heads and risers.

Fluidity and melting point are not equivalent terms, but in the manganese silicate system the most fusible slags are also fairly fluid, thus:

Fluidity of Manganese Silicate Slags
(Herty and Associates; Cooperative Bulletin 58)

% SiO_2	% MnO	Fluidity
0 to 10%	100 to 90%	Viscous
10 to 23%	90 to 77%	Fairly fluid
23 to 46%	77 to 54%	Very fluid
46 to 50%	54 to 50%	Fairly fluid
50 to 100%	50 to 0%	Viscous

Let us see how the information in Fig. 7, 8 and 9, the FeO-SiO_2 chart, the MnO-FeO chart, and the MnO-SiO_2 chart, can be of use to us in steelmaking. It has been noticed before by steel-

makers that if the entire charge of scrap is metal low in manganese and silicon — that is, a charge consisting almost entirely of rimmed steel — fairly good physical properties will be gotten from the resulting steel if the heat is melted down and tapped without any boil to speak of. However, if a charge is melted down of scrap which has a high percentage of silicon and manganese in it, and the heat is tapped without being oxidized and put through a boiling cycle, the steel will have inferior physical properties.

This is not too hard to understand, in the light of what has been said about oxides, since the heat when melting down will absorb enough oxygen from the air to oxidize most of the manganese and silicon in the scrap. The relative proportions of these two oxides in the steel are rarely, if ever, such that when they combine with each other the resulting slag system will have a low melting point. The oxide combinations actually have a high melting point and there is very little chance for these particles to coalesce and form larger particles which would be able, due to their greater size, to rise out of the steel.

However, if enough additional ore had been added to the heat which was high in silicon and manganese not only to completely oxidize the silicon and manganese in the steel but also to leave considerable FeO in the steel, this FeO would have become a part of the MnO-SiO_2 slag system, lowering the melting points and also making it more fluid. These more fluid particles would then be able to coalesce and float out of the steel.

It can therefore be seen that, after the melt-down, if the steel is ored until the slag on the top of the metal is black, it is a sure sign that enough ore has been added to completely oxidize the silicon and manganese and to leave considerable FeO behind in the metal. The resulting oxide particles form a fluid system which is rapidly eliminated to the slag.

This is a very important step in the working of a heat. If the steel is to be as free as possible from inclusions or oxide particles when it is tapped from the furnace, these oxide particles which are formed in the metal when it is melted down should be removed. However, we then run into this difficulty: When enough ore has been added to the heat to flux out the silicon and manganese inclusions, the steel will then contain more FeO than is desirable to have when the steel is tapped. In other words, the oxygen content will be so high that if the steel were tapped, the casting would be porous due to the gas which was in solution in the melt. Therefore the oxygen content must be lowered before the steel can be tapped.

Here is where carbon steps into the picture. It is to be remembered that the fluxing of the SiO_2 and MnO particles in the steel by the FeO can and should take place while the heat is still too cold to boil. For this reason ore should be added to the heat as soon as a pool is formed; enough ore should be added while the rest of the heat is melting to keep the slag over the metal a black color. When the metal has picked up enough temperature for the carbon to react with the oxygen in the steel, the boil will start. As this reaction continues, the oxygen content of the metal will gradually be reduced. When the boil dies down equilibrium is approaching; however the oxygen content in the metal will be lower if the residual carbon is higher, as can be seen from the carbon line in Fig. 6. Actual amounts are above and to the right of this curve because it represents true equilibrium, and time is insufficient in steelmaking to achieve equilibrium; also other conditions such as temperature are fluctuating. It is close to truth to say that if the steel is to have as little FeO in it as possible after the boil, the carbon remaining should also be only a few points below what is necessary when the steel is tapped. When the boil has stopped, the steel is left in a fairly clean condition, since the inclusions which were in it on the melt-down have been fluxed out by the FeO, and the FeO content left in the metal after the fluxing has been reduced by the carbon, and the bubbling of the gas has swept out many of the suspended particles. Of course during the boil the FeO content of the steel is continually being lowered since the oxygen is carried out of the bath as carbon monoxide gas.

The FeO which is in the slag will, continually during the boil, tend to leave the slag and enter

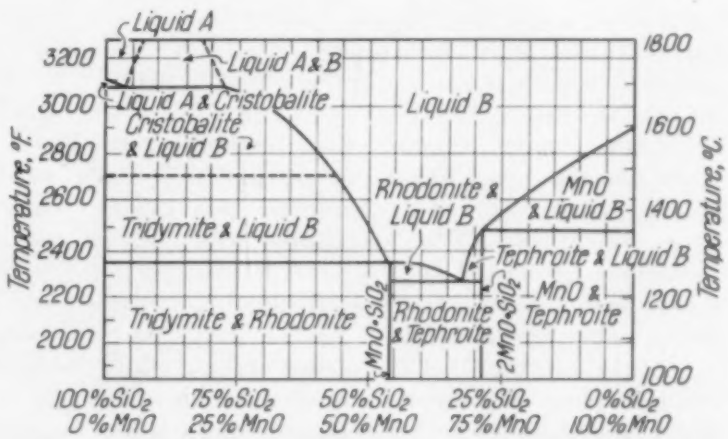
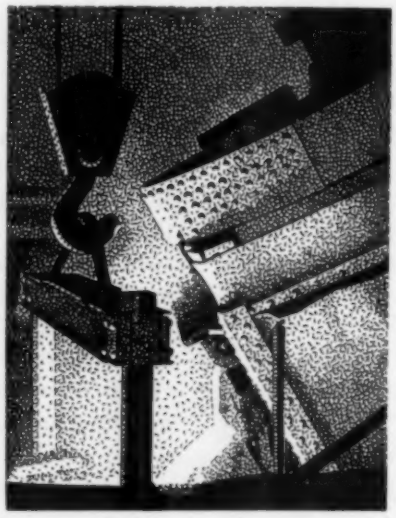


Fig. 9 — Equilibrium Diagram for Manganese Silicate Slags

the metal, since equilibrium between these two liquids requires a definite ratio between the FeO in the slag and the FeO in the metal. Therefore, at the end of the boil the slag has also lost enough FeO to change from a black to a pea green color, a sure indication of slag having a minimum of FeO in it. When this point has been reached, carbon's role as a deoxidizer is finished, since it has reduced the FeO as far as it possibly can.

To reduce the FeO content of the steel further, a more powerful deoxidizer than carbon will have to be used; that is, silicon or aluminum. Silicon (ferrosilicon) is commonly used in most shops. However, the silicon dioxide particles which are formed are not liquid at this temperature, and therefore will not coalesce and rise into the slag. Fortunately, if an addition is also made of silico-manganese, an alloy which contains silicon and manganese in the ratio of one to five, and enough added to raise the silicon content of the steel approximately twelve points (0.12%) a slag system will be formed that is very fluid, and the inclusions will coalesce and rise very quickly. Such slag particles are composed of approximately 60% MnO and 35% SiO_2, and Fig. 9 shows that they have a very low melting point and they are likewise very fluid.



Besides these large fusible inclusions there are also smaller inclusions, which analyze 43% MnO and 57% SiO_2. These particles do not have as low a melting point as the larger inclusions and therefore are not able to coalesce and rise as rapidly into the slag. However, if an addition of ferromanganese is made shortly after the silico-manganese addition, the manganese oxide content of these undesirable smaller inclusions will be raised, thus lowering their melting point, and they will then tend to coalesce and also rise up into the slag.

Good practice therefore calls for boiling the carbon down to just below the required analysis, at which time the slag should be pea green. Then deoxidize (kill) the metal with silico-manganese, followed shortly with a little ferro-manganese, and finally by ferrosilicon to bring the metal to specification.

It is important that the melter make a pretty good estimate of the condition of the steel after these additions have been made — that is, to know when the metal contains a minimum of oxides, both dissolved and as suspended particles. This will vary with the shop and the melting practice; each melter must determine it for himself. Conditions will vary primarily with the time cycle, the temperature of the bath, and the depth of bath.

At any rate, when the steel is at its cleanest is the time to add the other alloys necessary to give it the correct chemical composition. The heat should be tapped as quickly as possible after they have melted, since the longer it is held, the greater will be the amount of FeO which will leave the slag and re-enter the metal.

It is most common for melters to deoxidize their steel with ferrosilicon alone, adding it after the boil has boiled itself out and the steel is hot enough to be tapped. A few minutes after the ferrosilicon addition, most melters will take a sample of the metal from the furnace and pour it into a test mold. Its quietness is a measure of the deoxidation. A well deoxidized steel will spark very little, if any, and the steel in the mold will dish down in the center. If the steel does not dish down sufficiently, a further addition of ferrosilicon is made, enough being added to quiet the steel.

Many melters prefer to deoxidize their steel with ferrosilicon, as remarked above, since they can then take this test from the furnace to make sure that the steel is in a deoxidized state. If the steel were deoxidized with silico-manganese (enough being added to raise the silicon content 12 points) the steel would not be in a completely deoxidized state and a sample taken from the furnace would not show a completely sound steel. It is harder to judge from a sample of this kind whether the steel is sufficiently deoxidized than it would be from a sample to which, say, 40 points of silicon have been added.

It is the author's opinion that if the slag has reached a pea green color and has started to lump up slightly after the boil has boiled itself out, the steel can be deoxidized with silico-manganese followed by the manganese and silicon addition, and safely tapped *without* a quiet test being taken. If the metal is in the right condition before the deoxidizers are added, there is no necessity for the quiet test. Testing only keeps the metal in the furnace for a slightly longer time, and therefore *(Continued on p. 530)*

NICKEL ALLOY STEELS

Provide Essential Dependability

These Nickel steel parts for aircraft engines meet the rigid requirements and specifications of the Army Air Forces.

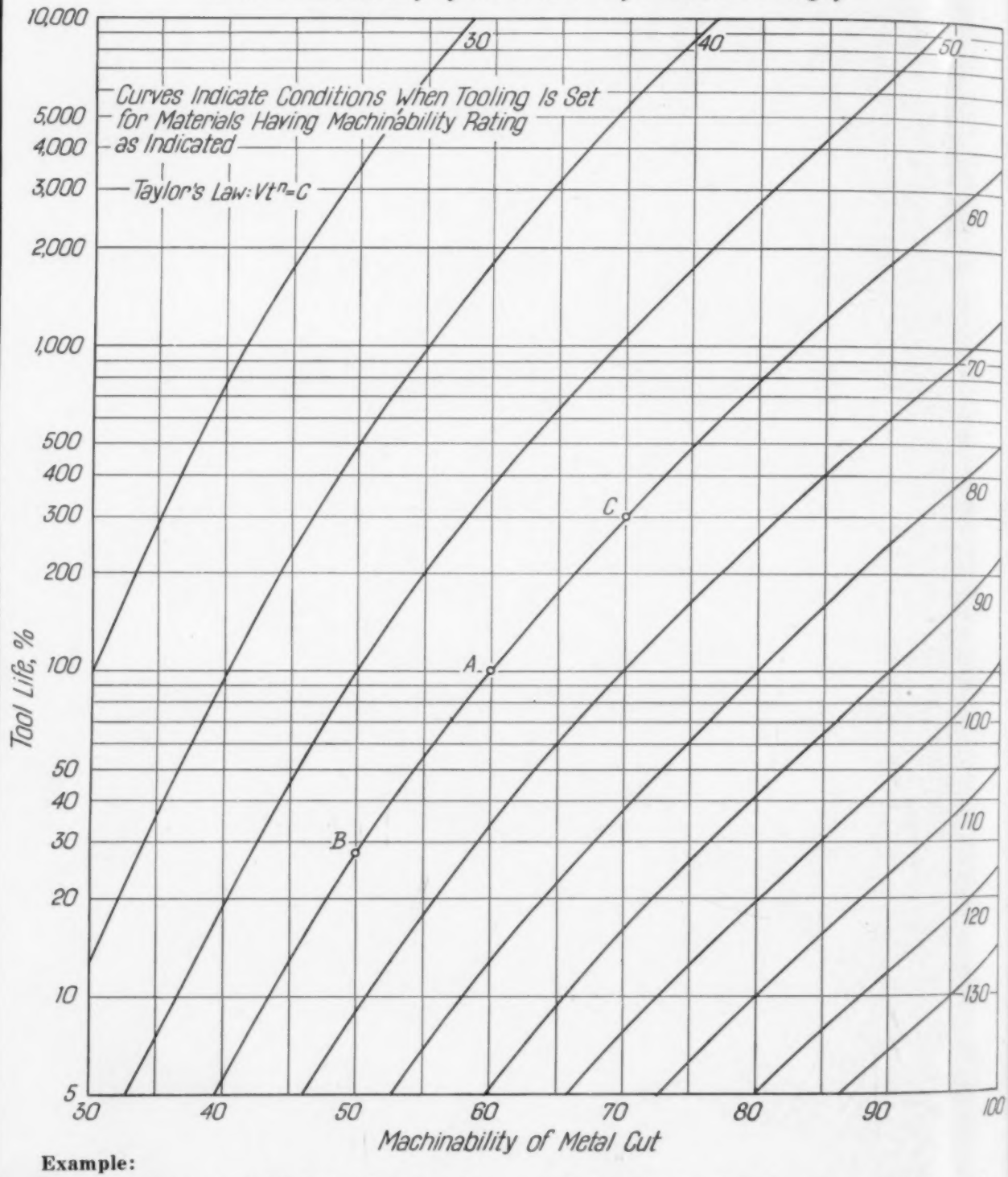
Turned out by the thousands by American Safety Razor Corporation, they satisfy the engine builders' demands for high mechanical properties, minimum distortion after heat treatment, close tolerances and thorough reliability in service.

We invite consultation on the use of Nickel or Nickel alloys in your products or equipment.

THE INTERNATIONAL NICKEL COMPANY, INC. 67 WALL STREET NEW YORK 5, N. Y.

Tool Life Versus Machinability of Metal

Chart Showing Change in Expected Tool Life With Variations in the Machinability of the Metal. By Nelson G. Meagley



Example:

If tooling is established for a machinability rating of 60 and the material being cut actually has a machinability rating of 60 (Point *A*), the expected tool life will be 100% of normal. If the machinability of the metal falls to 50 (Point *B*) — other conditions of the tooling set-up remaining constant — tool life will drop to 27% of normal. If the machinability improves to 70 (Point *C*) then tool life becomes 300% of normal.

The Supersonic Reflectoscope for Interior Inspection

By Floyd A. Firestone*
Departments of Physics and Engineering Research
University of Michigan
Ann Arbor, Mich.

THE SUPERSONIC reflectoscope is an instrument for the measurement or the non-destructive testing of solid parts for flaws by sending supersonic sound waves into the part and observing reflections from the boundaries of the part or from any flaws within it. The reflectoscope has been developed at the University of Michigan in a research program which has continued for several years.

The principle of the reflectoscope as applied to the inspection of a block of metal is sketched in Fig. 1. A quartz crystal makes effective contact with the work through a thin film of oil which is squirted onto the surface of the work. The upper and lower faces of the thin flat crystal are provided with conductive coatings. When an oscillatory voltage is applied between these coatings the crystal grows thicker and thinner in synchronism with the electrical oscillations. This causes the lower face of the crystal to vibrate and thereby radiate sound waves of very short wave length through the oil film into the work. By proper choice of the thickness of the crystal it will give a "thickness resonance", and correspondingly increase the strength of the sound waves radiated. The sound waves are not radiated continuously because the electrical impulses are imposed only for a short time interval; typical operation would consist in applying 500 volts to the crystal at a frequency of 5 Mc. (5 million cycles per second) for 1 microsecond (1 millionth of a second).

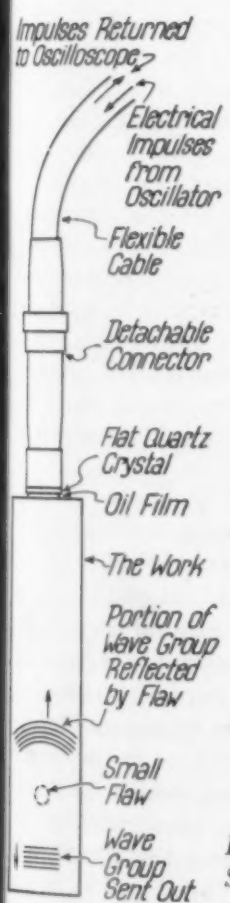


Fig. 1 — Principle of the Supersonic Reflectoscope

Thus a group of only five waves is radiated; the wave length in steel or aluminum at this frequency is approximately 0.050 in. and the total length of the wave group is 0.250 in. If the crystal is 0.5 in. square the waves will be radiated in a beam, like a searchlight beam, whose cross-section is also 0.5 in. square. Since the velocity of longitudinal sound waves in steel or aluminum is approximately 250,000 in. per sec., the waves travel 1 in. in 4 microseconds, and if the block shown in Fig. 1 has a vertical dimension of 4 in. the wave group will be approaching the bottom of the piece (as shown) about 15 microseconds after having left the crystal. This wave group will be reflected from the bottom face of the work and will get back to the crystal 32 microseconds after having been sent out.

*Professor Firestone is also consultant for Sperry Products, Inc. of Hoboken, N. J., manufacturers of the equipment described.

A quartz crystal contacting the work through an oil film sends into the work a few sound waves of short wave length. This wave group is reflected from the side of the work most distant from the crystal and upon returning and striking the crystal generates in it a voltage whose time of arrival is indicated on a cathode-ray oscilloscope. Any flaw is detected by its reflecting a part of the wave group, and this reflection arrives at the crystal before the reflection from the distant side of the work.

The quartz crystal also has the property that when it is subjected to the oscillatory pressure caused by the impingement of the sound waves against its face, it generates a small voltage between its coatings, which (in the present example) might be of the order of magnitude of 0.05 volt. This small voltage is amplified by electron tubes and indicated on a cathode-ray oscilloscope in such a manner as to enable the time of round-trip flight of the waves to be measured.

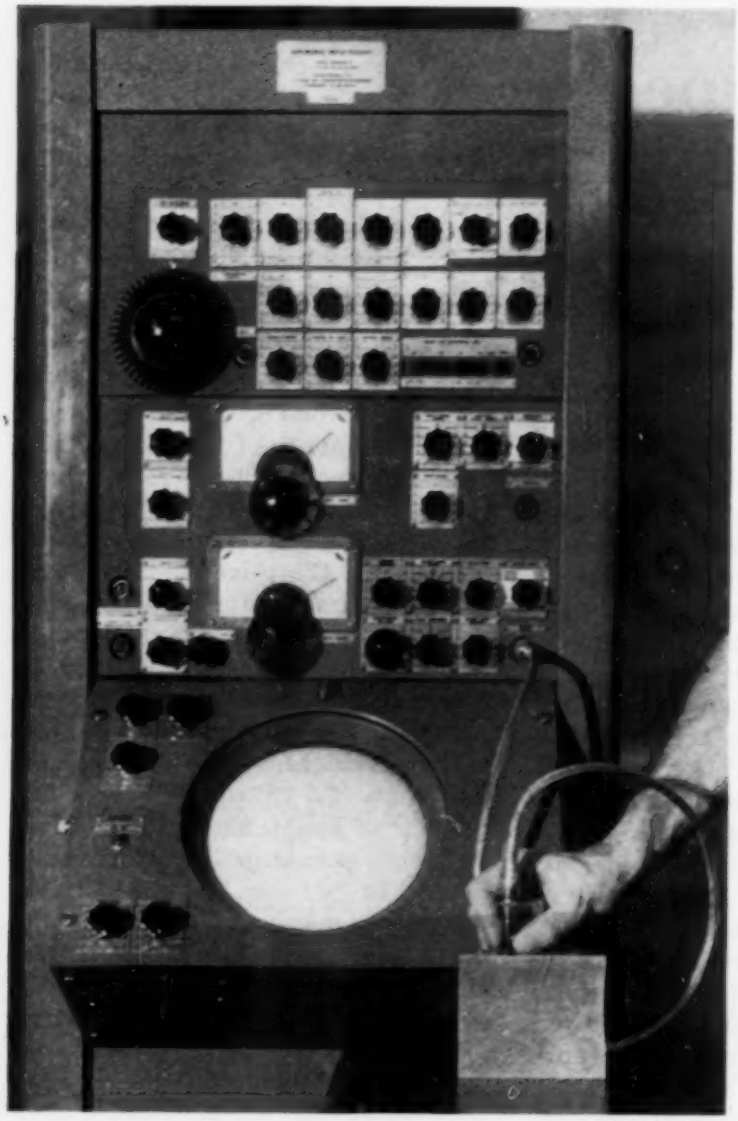


Fig. 2 — Closeup of Panel of Type A Reflectoscope Showing the 9-In. Oscilloscope Screen. The crystal is being held against a block under test. A fixed focus camera on a light tripod may be quickly attached above the screen to photograph reflectograms at will, although visual observation usually suffices

If now the block of Fig. 1 has a small flaw 3 in. below the surface on which the crystal rests, a small amount of the wave energy which passes it will be reflected back toward the crystal, and will arrive at the crystal 24 microseconds after having been sent out. *Thus the presence of an interior flaw is indicated by the receipt of a reflection back at the crystal before the reflection from the other side of the piece gets back to the crystal.* By measuring the time of round-trip flight of the reflection from the flaw we can determine its distance from the crystal with an accuracy of less than one-sixteenth of an inch, and we can locate its position laterally to within less than one-eighth of an inch by noting that we will get strongest reflection from the flaw when it lies on the line directly under the center of the crystal.

For convenience, the whole process of sending out the wave group and observing reflections is repeated 60 times per sec. so that we appear to have continuous indication of flaws on the oscilloscope; the crystal may be slid along the surface, thereby continuously inspecting the region along the line directly beneath the crystal. The same quartz crystal is ordinarily used both for sending and receiving the waves.

There is nothing occult about supersonic waves in metals; the word "supersonic" here refers merely to the fact that the frequency of the waves is higher than audible. Supersonic sound waves are better than audible sound waves for inspecting metals because the short wave length supersonic "sounds" are reflected from small flaws, while audible sounds of long wave length would flow around and past the flaws without appreciable reflection. In order to get appreciable reflection from a flaw the wave length must not exceed the smallest lateral dimension of the flaw by too large a factor.

A second useful property of short wave length sound waves is our ability to direct them in a beam. While we are accustomed to the fact that audible sound waves in the air bend around corners, the short wave length supersonic waves used by the reflectoscope appear to travel in straight lines like light waves, and for the same reason — their short wave length. The longitudinal waves, which the reflectoscope normally uses, travel through the interior of the metal part and the particles of metal vibrate in the line of propagation as the waves pass.

As a microsecond is not very long, being the time required for a beam of light to travel approximately 1000 ft., the apparatus for carrying out this principle in a way which will be

useful in industry must be both refined and rugged. The reflectoscope as it was developed at the University of Michigan is shown in Fig. 2. Although some of these Type A machines have been used in production, they may more properly be considered as laboratory instruments, while the model for general industrial use is the Type B shown in Fig. 3 as developed by Sperry Products, Inc.

Types A and B are equally sensitive, but Type A has a more detailed system of timing marks for measuring distances (compare Fig. 4 and 20), although the preliminary adjustment of these timing marks requires the manipulation of the extra set of knobs shown on the upper panel of Fig. 2. Most of the illustrative reflectograms shown in this paper were made with Type A, merely because these photos happened to be available at this writing. While Type A has a considerable number of knobs which may require adjustment when making the setup for a new type of test, in routine operation all knobs are left fixed (with the possible exception of the amplification control). Thus a skilled man is required for setup, but routine operation can be carried out by unskilled help. The Type B instruments, it is to be noted, have been simplified in this respect.

In Fig. 2 the crystal is being held against a test block, 4 in. through, as was assumed for Fig. 1. Fittings holding crystals of other frequencies (from 0.5 Mc. to 12 Mc.) may be plugged onto the end of the cable; lower frequencies and longer wave lengths permit greater penetration of coarse grained materials, while high frequencies and short wave lengths permit the detection of the very smallest defects. The flexible cable may be as long as 10 or 20 ft. at some small sacrifice of sensitivity. The various knobs on the panels are for tuning the circuit which energizes the crystal, for focusing the oscilloscope tube, controlling the oscilloscope sweep, and introducing the timing marks. The 9-in. diameter screen of the oscilloscope tube can be seen in the center of the instrument; the screen is slanted for ease of observation when working at the bench.

Although visual observation of the screen is the usual practice, when it is desired to record reflectograms a fixed focus camera on a tripod can be attached in a few seconds. It was with such a camera that the reflectograms shown in the remainder of this paper were obtained. The detailed principle of operation and a number of illustrative uses are set forth in the captions under the reflectograms on the following pages.

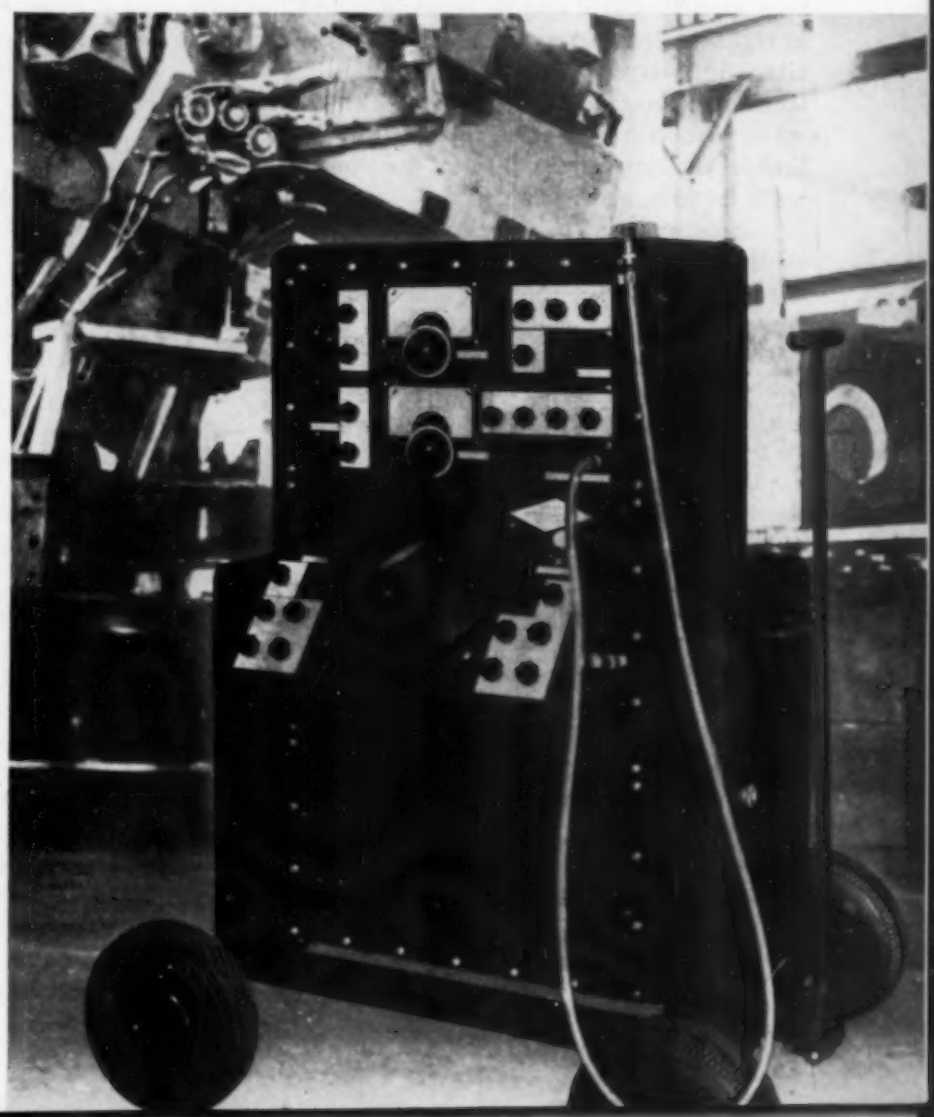
Additional Refinements

When the flaw is closer to the crystal than 0.5 in. the waves reflected by the flaw may be received before the transmitted wave train ends, thus preventing its detection. This problem has now been solved by special methods.

When the work is curved, the crystal may be ground to fit the curve. The waves then converge toward the center of the work and diverge beyond the center. All parts of the interior can be tested by moving the crystal around the surface. The curved crystal would also be advantageous, for instance, for measuring the wall thickness of a pipe or tank.

Sometimes the flaw is so situated that there is no region on the surface at which a crystal can

Fig. 3—Type B Sperry Reflectoscope



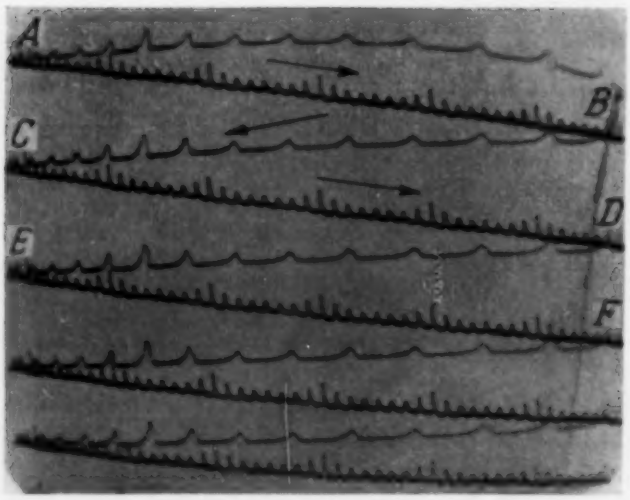


Fig. 4 — Oscilloscope Pattern of Sweeping and Timing System, Type A Equipment

Pattern appearing on the screen when the crystal is not being energized — a time scale formed by the green spot-light of the oscilloscope traveling along the zigzag path *A-B-C-D-E-F*.....Each microsecond the spot is deflected slightly upward so as to notch the line; every eighth notch is higher, to assist in counting. There are eight of these higher marks per zigzag so that it requires 64 microseconds to traverse one zigzag.

be placed so waves can be transmitted to the flaw at right angles to the surface on which the crystal sits. Such is true of railroad axles which sometimes develop fatigue cracks inside the wheel seat where the axle is of larger diameter than its end. Special devices have also been developed whereby such flaws can be detected.

A connection for a second cable is provided so that one crystal can be used for sending out the waves and a second crystal placed elsewhere for picking up the waves. However, operation with a single crystal is so much more convenient that the double crystal is seldom used.

When the surface of the work is quite rough — for instance, the surface of a casting — the crystal makes poor effective contact with the work and the sensitivity is considerably reduced. It is advisable under these circumstances to touch a portable grinder to the surface. A rough turned surface is also sufficiently good.

If a crystal is placed against the wall of an *empty* tank a long series of reflections back and forth through the metal wall will be obtained. When the tank is filled with liquid it quickly absorbs the successive reflections so that only a *few* reflections appear on the oscilloscope screen. The level of liquid in a tank can therefore be determined merely by sliding the crystal up and down the outside, and observing the level at which the number of successive reflections sud-

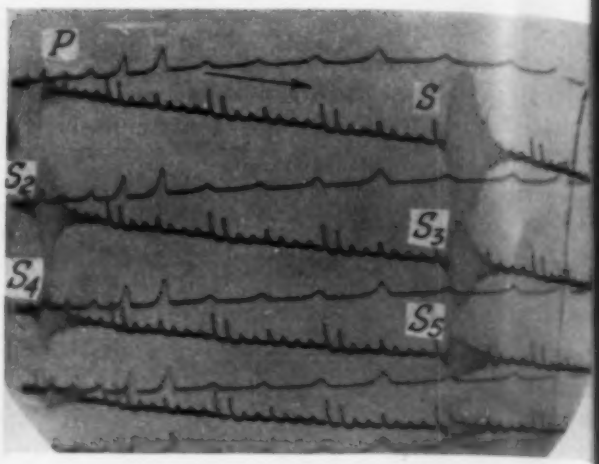


Fig. 5 — Bottom Reflections. The crystal is now energized at intervals and is in contact with a 4-in. block having no flaw in the path of the waves sent out by the crystal

Any oscillatory voltage across the crystal shakes the oscilloscope spot vertically and thereby widens the line. The crystal was first energized by 500 volts for 1 microsecond when the oscilloscope spot was at *P*; indicated by a widening of the line. While the group of sound waves was traveling through the block and being reflected back to the crystal the oscilloscope spot was traveling toward the right toward *S* in the top line; each notch represents a microsecond interval. When the returning waves struck the crystal the line was broadened at *S*, exactly following the 32-microsecond mark. (In fact, since it takes 8 microseconds for the sound wave to go through 1 in. of aluminum or steel and return, we think of the time scale in the reflectogram as a distance scale, considering the interval between the longer marks as inches which are divided into eighths.) The reflection at *S* therefore begins just following the 4-in. mark. When the waves strike the crystal they do not stop but are reflected back through the block for additional round trips and each time the waves strike the crystal a reflection is indicated — as for instance at the 8-in. mark at S_2, the 12-in. mark at S_3, the 16-in. mark at S_4, and so on. Since there are 8 in. per horizontal line (counting the return sweep) and the block is 4 in. through, the successive reflections should form two vertical columns. In practice, the exact time value of the time marks is modified until this relation holds, by adjusting the inch marks to be accurately inches, although the timing marks are then not accurately microseconds. If we were looking for a flaw, the only portion of this pattern which we would inspect would be the top line as far as the 4-in. mark; since no reflection appears in that region, we know there is no flaw in that part of the block which lies under the crystal.

denly changes. Another procedure would be to mount the crystal permanently in the bottom of the tank and shoot the waves through the liquid, thereby obtaining a reflection from the upper surface of the liquid. The time of receipt of this reflection would be a measure of the height of

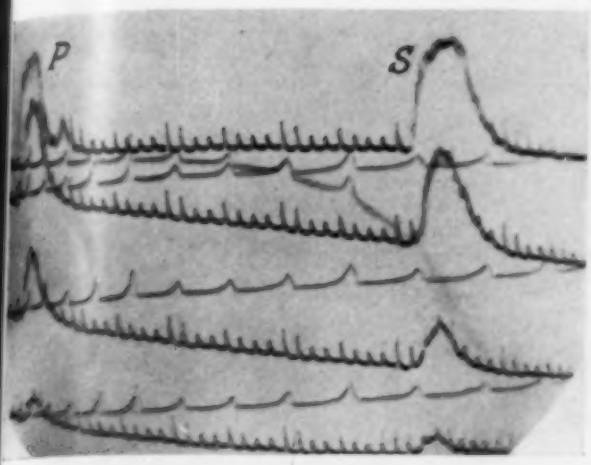


Fig. 6 — Visibility of Bottom Reflection Improved

Same as Fig. 5 except that, to improve visibility of the reflection, the spot has been deflected upward instead of being shaken up and down. Again no flaw. It is important to note that the entire process of energizing the crystal, sending out the waves, sweeping the oscilloscope spot, putting in time marks, and obtaining reflections, is repeated 60 times per second, so that the indications on the oscilloscope appear to the eye (through the phenomenon of "persistence of vision") to be continuous and they do not change until the crystal is moved to a new spot. Each reflectogram is a half-second exposure and represents 30 sweeps of the light spot, superposed; note the accuracy of registry. By continuously moving the crystal along the work while observing the reflectogram, one quickly inspects the entire interior. Compare Fig. 7.

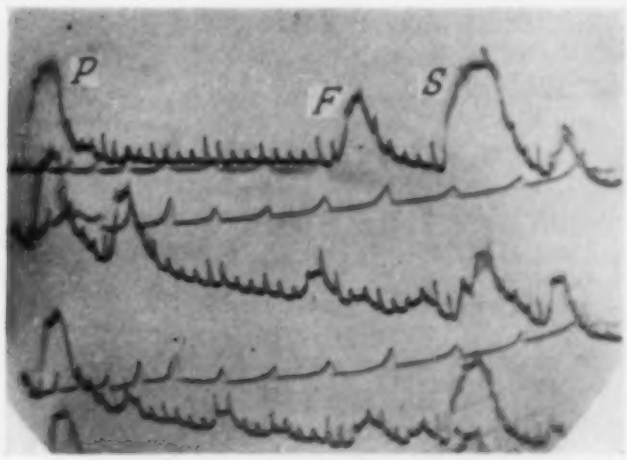


Fig. 7 — Flaw Detection

On the same 4-in. block as Fig. 6 the crystal is now held over a test flaw, 3 in. below the surface, consisting of a 0.012-in. hole drilled ¼ in. into the block so it is struck by the waves broadside. The large reflection from the hole appears at *F* just following the 3-in. mark and preceding the reflection *S* from the other side of the piece which just follows the 4-in. mark. Much smaller flaws than this have been detected; a spherical hole 0.005 in. diameter and about 3 in. from the crystal can be detected; a 0.060-in. spherical hole 5 ft. from the crystal can be detected if the material has a small grain size. Metal can be penetrated about 10 ft., the exact range depending on the grain size and the wave length. Higher frequencies and shorter wave lengths have shorter range but will detect smaller defects. All of the reflectograms shown here were taken at a frequency of 5 Mc.

the liquid column (although this would be influenced somewhat by liquid temperature and composition, both of which influence the velocity of sound in the liquid).

In the testing of rolled shapes it is often most convenient to inspect the bloom or billet from which the shapes are rolled and then crop out the flaws or the flawed lengths from the billet, thus keeping them from being rolled out into the finished material. Since sound metal can be penetrated to a depth of the order of 10 ft., very large blooms can be tested.

The reflectoscope can be used for determining holes or unfused areas in welds, but it does not directly measure the strength of the weld except insofar as the strength is influenced by the presence of such flaws or unfused areas. Certain cases have been observed where a weld was completely continuous and indicated no reflection on the reflectoscope, but was nevertheless found to be weak by breaking. Stresses produced by the sound waves are too feeble to break even the weakest weld.

Acknowledgments — I am indebted to Julian R. Frederick for his contributions during the many years which he has spent in constructing and testing the intricate experimental equipment for this development. I also wish to acknowledge the contributions of William G. Langton, and the theoretical studies made by Daniel S. Ling, Jr.; also the contributions of Ralph B. DeLano, who has been responsible for much of the develop-

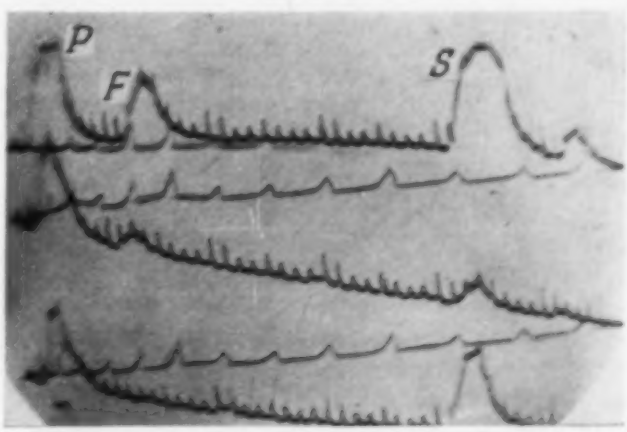


Fig. 8 — Same Flaw Detected From the Opposite Side

The block has been turned over so that the reflection from the test flaw is 1 in. from the crystal and shows at *F*.

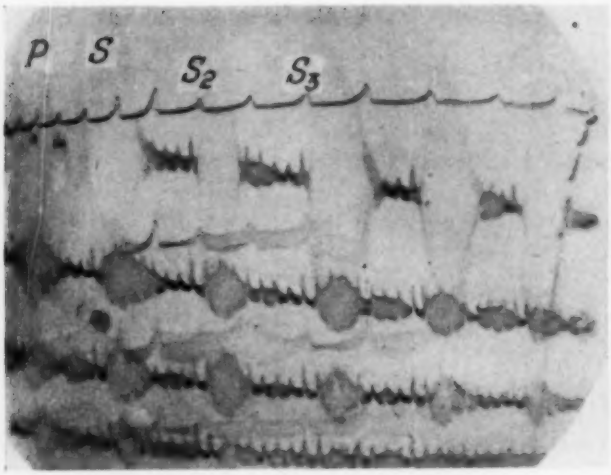


Fig. 9 — Measurement of Wall Thickness

To determine the wall thickness of a cored casting or of a pipe carrying corrosive material, where the inside surface is inaccessible, the crystal is placed against the wall. A series of successive reflections is obtained and the average distance between them, read off the inch-mark scale, is the thickness of the wall. This shows the series of reflections through a wall 1 in. thick; note that a reflection follows each 1-in. mark. Accuracy is of the order of 5%, and depends on the smoothness, flatness and parallelism of the wall faces.

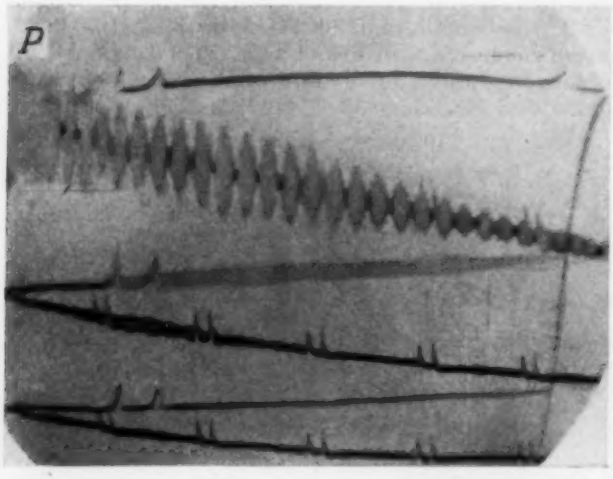


Fig. 10 — Measurement of 3/16-In. Wall

ment of the Type B model, and of H. C. Drake, both of Sperry Products, Inc. This development has been supported, through the Department of Engineering Research of the University of Michigan, by United Aircraft Corp., General Motors Corp., and Sperry Products, Inc.

References — Bergmann-Hatfield. "Ultrasonics and Their Scientific and Technical Applications," John Wiley and Sons, 264 pages, 1938. Robert W. Wood. "Supersonics, the Science of Inaudible Sound," Brown University, 159 pages, 1939. U. S. Patent 2,280,226, F. A. Firestone. Application: May 27, 1940; granted April 1, 1942; also other patents pending.

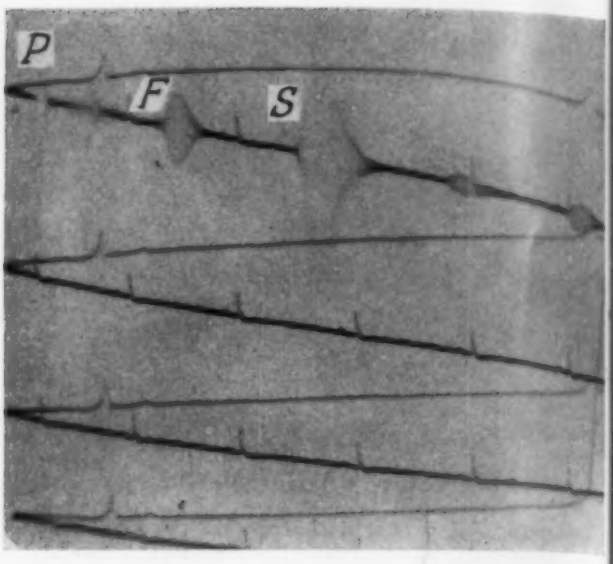


Fig. 11 — Lamination Detection

The crystal is placed against a 2½-in. rolled steel plate; the reflection from the opposite surface is at *S* while there is a moderate sized flaw at *F*, halfway through the plate. Compare Fig. 12.

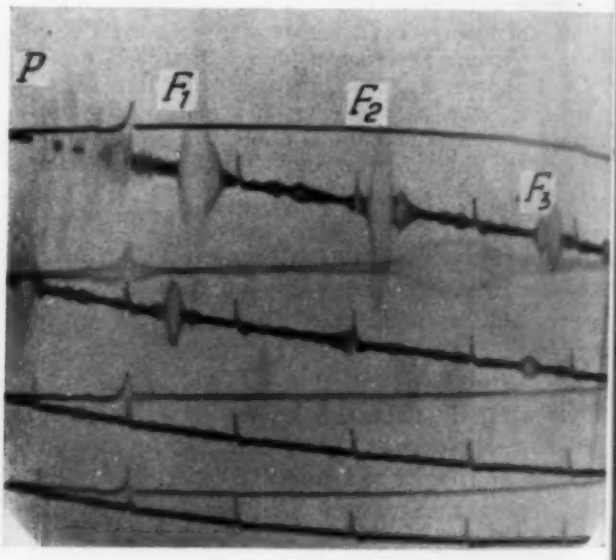


Fig. 12 — Lamination Detection

The crystal is now against a different spot on the same sample as Fig. 11. Here the plate has a lamination about 1½ in. from the crystal and of projected area greater than the ½-in. square of the crystal. The outgoing waves from the crystal are therefore *completely* reflected by the flaw (none from the opposite surface of the plate). Reflections F_1, F_2 and F_3 are successive reflections between flaw and crystal. By moving the crystal over the surface of the plate the laminated area can be accurately outlined merely by noting where the reflectogram changes from Fig. 11 to Fig. 12. The thickness of the lamination is of no consequence; 0.0001 in. of separation will give as large a reflection as any greater spacing. (The interface between two Johansson gage blocks wrung together gives a good reflection — and also considerable transmission.)

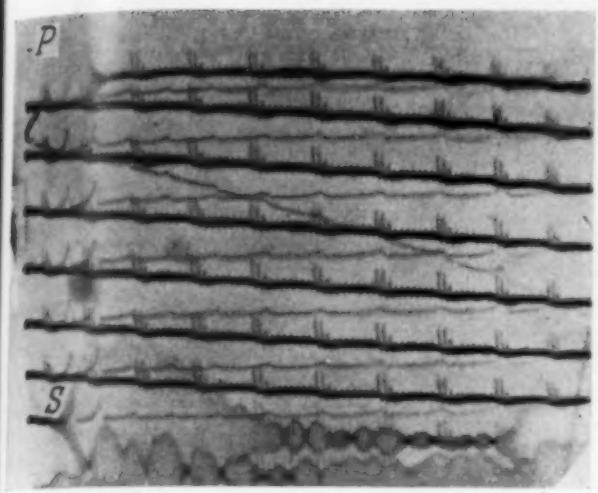


Fig. 13 — 70 In. of Sound Steel

The crystal is held against the *end* of a ¼-in. plate 70 in. long. A large reflection *S* is obtained from the opposite end of the plate, and no intermediate reflections are observed from internal flaws. Ten or 20 ft. of sound metal can be penetrated if its grain size is not too large. Compare Fig. 14.

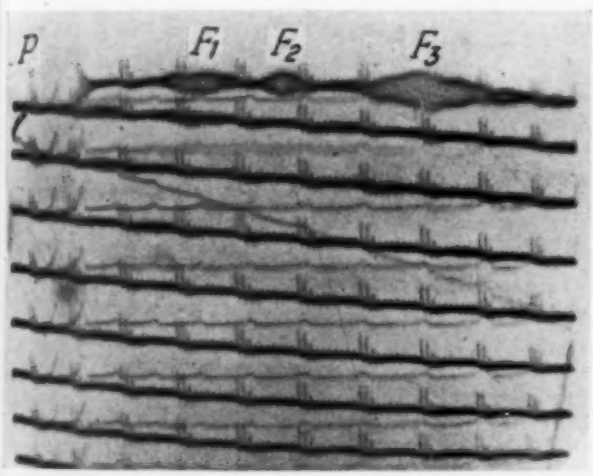
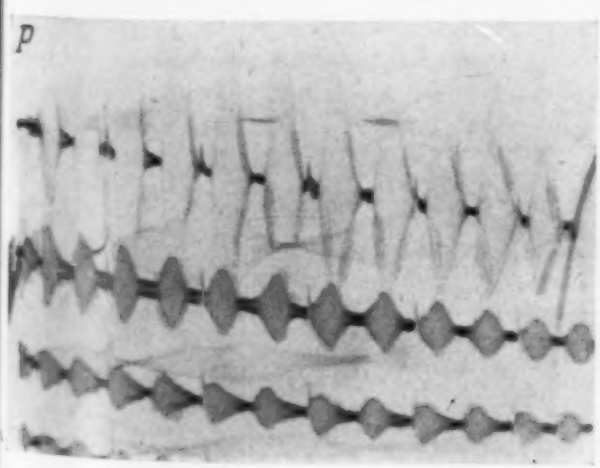


Fig. 14 — A Plate Similar to Fig. 13, but Full of Small Inclusions Which Give Random Reflections F and Prevent Any From the Opposite End



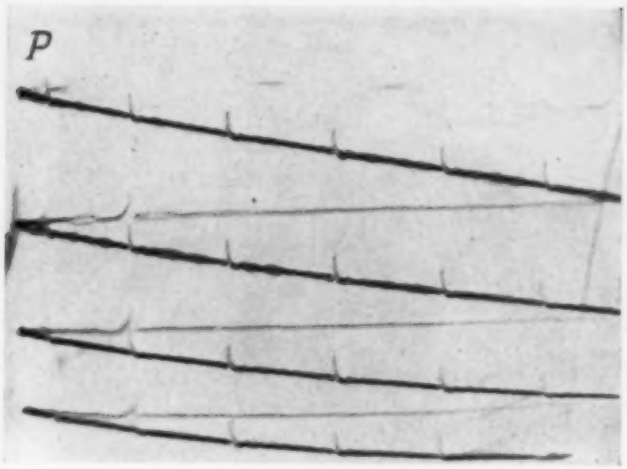


Fig. 16 — Defective Bond

Same plate and same conditions as Fig. 15 but with the crystal above a spot having bad bond larger in area than the crystal itself. In this case the bond has caused the waves to be absorbed (probably due to the presence of some flux). If the area of bad bond were clean, a series of reflections ¼ in. apart would have been observed. In either case the area of bad bond can be easily outlined by moving the crystal.

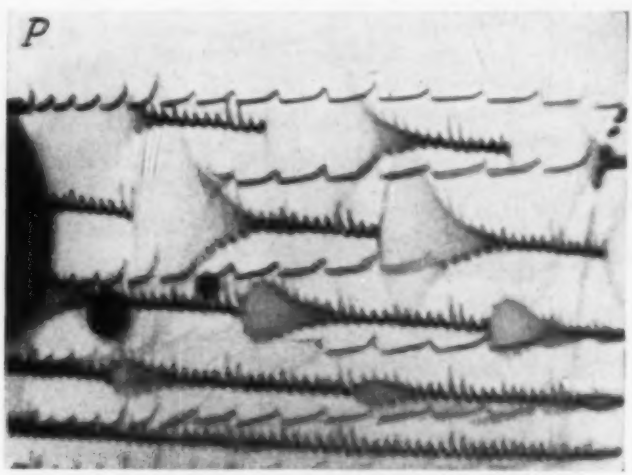


Fig. 17 — Measurement of Average Grain Size

A piece of ½-in. brass plate, cold rolled, was cut into strips 2 in. wide which were annealed at different temperatures to produce large differences in grain size. This one has an average grain size of 0.03 mm., as measured by microscope. Reflections were obtained through the 2-in. dimension. Note that 12 successive reflections are observable in the above reflectogram. Compare Fig. 20 and 21.

Fig. 15 (at Left) — Bond on Faying Surfaces

A plate ½ in. thick was built up of two ¼-in. plates bonded together by an undisclosed method. The reflectogram shows a long series of reflections exactly ½ in. apart, and none from the bonded interface. The plate appears to be a solid piece. Compare Fig. 16.

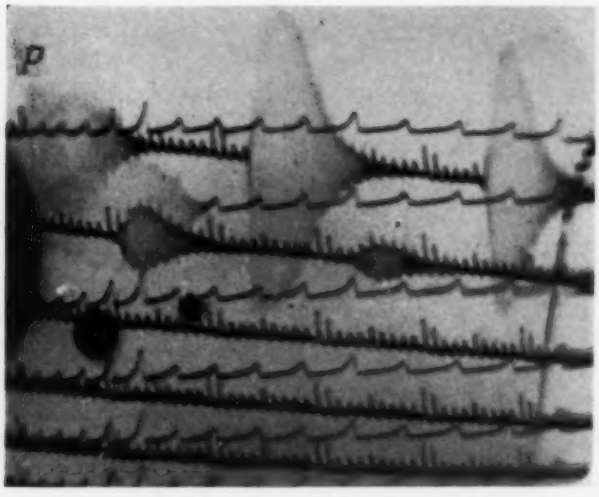


Fig. 18 — Measurement of Average Grain Size

Same as Fig. 17 but the brass has an average grain size of 0.075 mm. as measured by microscope. Although the sensitivity is the same as before, only six successive reflections are observable in this reflectogram.

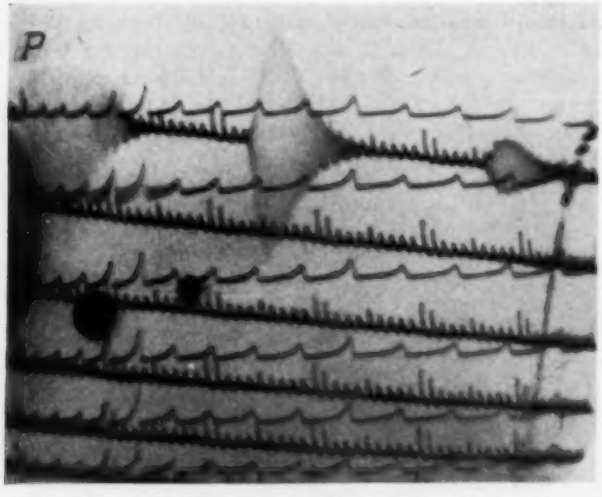


Fig. 19 — Measurement of Average Grain Size

Same as Fig. 18 except that the brass has an average grain size of 0.105 mm. Only three successive reflections are visible. Thus by suitable calibration, the rate at which the waves are scattered or absorbed may be used as a measure of average grain size. By proper choice of frequency and wave length this method can be made sensitive in different ranges of grain size. The frequency used here was 5 Mc., corresponding to a wave length in brass of 0.88 mm.

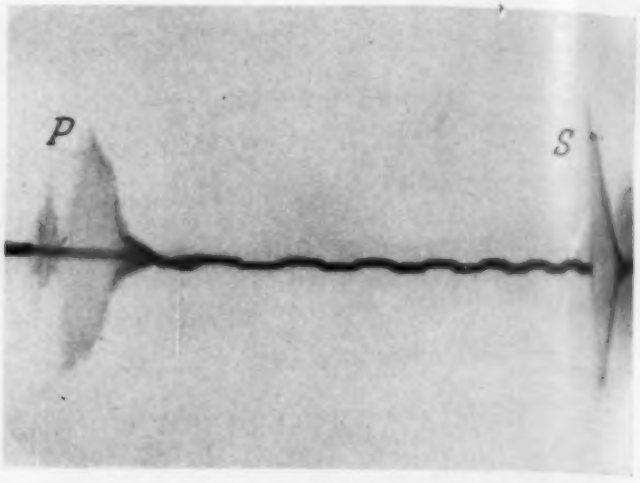


Fig. 20 — Weld Testing With Type B Reflectoscope

Two pieces of steel, 6 in. diameter, were electrically butt welded. *P* is the original pulse and *S* the reflection from the opposite end of the assembly (8.4 in. from the crystal). This was taken at a place where the weld is continuous. Each square wave indicates 1 in. Compare Fig. 21 and 22.

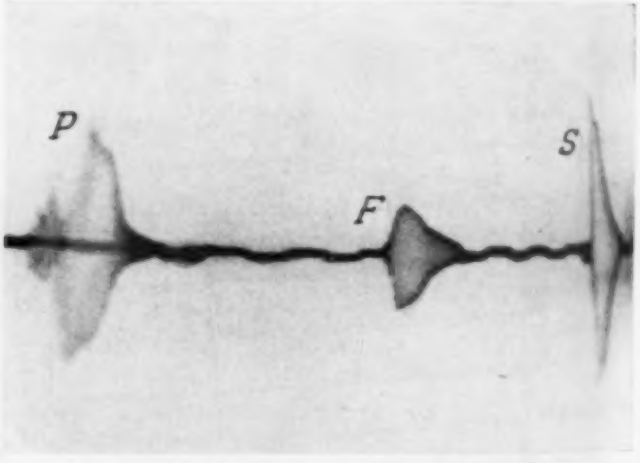


Fig. 21 — Same as Fig. 20, But Taken at a Place Where the Weld Was Only Partially Continuous, Yielding a Reflection F From the Weld and S From the Other End

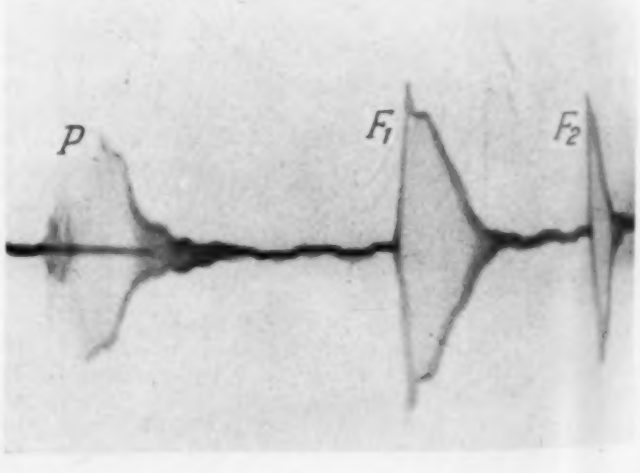


Fig. 22 (Right) — Same as Fig. 20, But at a Place Where There Is no Weld; F_1 Is the First Reflection From the Weld and F_2 the Second

By Eric N. Simons
Edgar Allen, Ltd.
Sheffield, England

The Supersonic Flaw Detector

ONE of the great disadvantages of many standard tests applied to metallic parts by engineers is that they necessarily involve either the total destruction of the part tested, or call for the production of special test pieces, which, it is often argued, can never exactly represent the condition of the part itself.

By means of supersonic detection, an old British invention, metallic and other parts may be tested non-destructively. It employs the device of sending out a train of supersonic waves so short that the wave length is very much less than the distance between the boundaries of the medium being investigated. The transmitted and reflected wave-trains are shown on a cathode-ray tube (screen of an oscilloscope) in such a way that they do not interfere, and it is possible to detect an extremely small echo, even though it may be followed by other echoing reflections containing hundreds of thousands of times as much energy.

The supersonic waves mentioned in the last paragraph are physical impulses — waves of alternating compression and rarefaction in the atomic spacings of the liquid or solid being tested, exactly like sound waves in air but *very* much shorter. These vibrations are set up by high frequency currents, although the electrical devices, as will be shown later, are merely means for inducing the compression waves and recording their echoing reflections. An early use of the principle (if not the earliest "practical" use) was for depth sounding; the echo from the bottom of the ocean at 2300 ft. returned in about 1 sec., and the measurement of time intervals for such considerable distances was relatively easy. However an echo from an interior defect, say at the center of a 4-in. steel billet, gets back in such an infinitesimal time that advanced electronic equipment is necessary for their detection, amplification and registry.

The pressure waves are set up by quartz crystals in close contact (through a film of oil) with the body that is to be tested. Quartz has the property of changing its atomic spacing (volume) with changes in an electrical current passing through it. These volume changes synchronize with the electrical changes without time lag. If, therefore, a rapidly oscillating current is sent through such a quartz crystal, its surface will move in and out exactly in step with the electrical current, and if the crystal is in close contact with a solid, these small, rapid pushes start pressure waves in the substance being tested. In a contrary manner, a returning pressure wave causing a small volume change in a receiving crystal will generate corresponding electrical currents therein, and these may be amplified by electronic tubes to a magnitude where they can be detected by our senses, as on an oscilloscope.

The desirable timing effect is obtained by the use of an electronic "triggering" system. This first sets the cathode-ray time base in operation, and then a short time later transmits a few cycles of high frequency current.* The transmission mark, the echo and later reflections cause a transverse deflection of the cathode-ray spot, and the result is an oscillogram of the type shown in Fig. 1 and 2. The transmission time mark at the left of each mark is caused by electromagnetic induction effects accompanying transmission, picked up by the receiver amplifier.

To secure this clarity of indication it is

*EDITOR'S FOOTNOTE — Speaking quantitatively: The time base may be sent out and ten-millionths of a second later five cycles of five-megacycle current may follow, this taking one-millionth of a second. The system is then quiet for one-sixtieth of a second, and the signals repeat; in this way the successive paths traced 60 per sec. by the moving spot of light on the oscillograph screen repeat often enough so the eye observes them as persistent curves. Supersonic impulses set up by five-megacycle current have a wave length of about $\frac{1}{4}$ in.; the effect in the steel or aluminum being tested is therefore the rapid passage of an almost instantaneous disturbance about $\frac{1}{4}$ in. thick, 60 times a second.

essential that the successive echoes should die out before another transmission occurs. Hence the necessity for a long time between transmissions, as compared to their individual durations (on the order of 1/60 sec. vs. 0.000001 sec.).

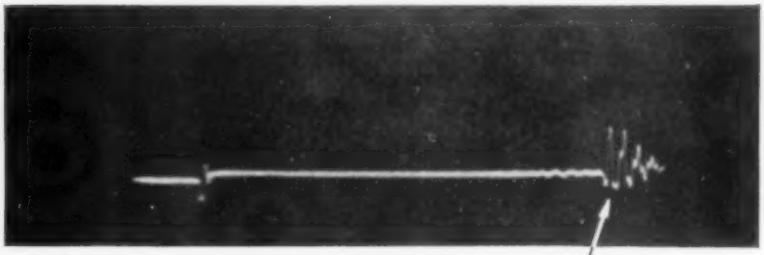
The apparatus comprises a power pack, transmitter receiver system, transmitter driver, receiver amplifier, trigger unit and time base, all of which are schematically shown in Fig. 3. The equipment (Fig. 4) as manufactured by Henry Hughes & Son, Ltd., of London is quite compact and portable, and is designed to detect flaws within a region of approximately ½ in. to 12 ft. from the surface, and many experiments have been carried out which show that it is, in fact, capable of yielding useful results between these limits.

The cathode-ray set, at top of Fig. 4, is conventional in wiring and construction, as is also the amplifier unit with its six stages of amplification to energize the reflected impulses sufficiently to operate the oscilloscope, and the power pack. The discharge time base and the trigger-driver unit have somewhat specialized wiring diagrams; their illustration and explanation, probably, should be given in a paper to be read by electrical engineers rather than by metallurgists.

The principle on which the flaw detector is based is the use of a wave length short enough to secure rectilinear propagation of supersonic radiation. This condition is reached when the obstacle is large in comparison with the wave length; detectable reflection occurs when the target has dimensions of the order of a wave length or greater. Most known materials will transmit supersonic waves whose wave length is a millimeter or less over a useful range of distance, and obviously this opens up the prospect of detecting flaws in the interior of bodies opaque to light.

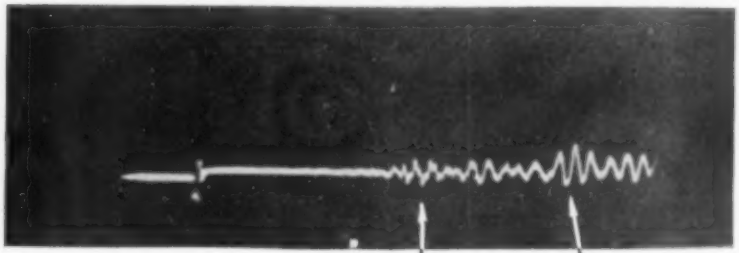
A sound sample of steel giving the oscillogram of Fig. 1 may be compared with a sample containing hair-line cracks (Fig. 5). It should be specially noted that Fig. 5 shows virtually no bottom echo, and it is suggested that this is a better guide to the extent of a flaw than the magnitude of the flaw

Fig. 1 — Typical Oscillogram From Sound Billet, Showing Time Mark at Left and no Echo Except From Bottom Surface. Detector placed on natural surface of billet after oiling



Bottom echo only

Fig. 2 — Oscillogram From Similar Billet as in Fig. 1, Showing Echo From Flaw 1¾ In. Above Bottom



Echo from flaw

Bottom echo

echo taken by itself. In this oscillogram the echo from the flaw is slightly more intense where the bottom echo vanishes, but this is not always true.

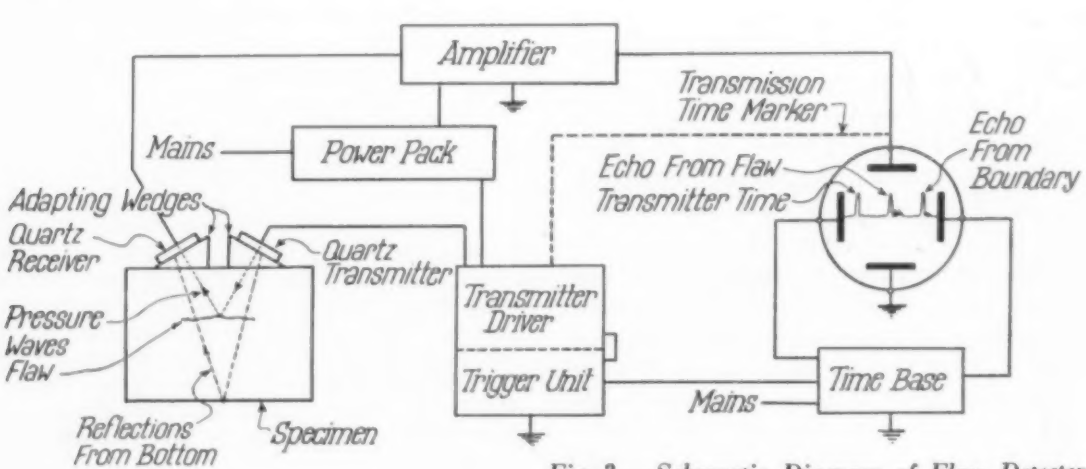


Fig. 3 — Schematic Diagram of Flaw Detector

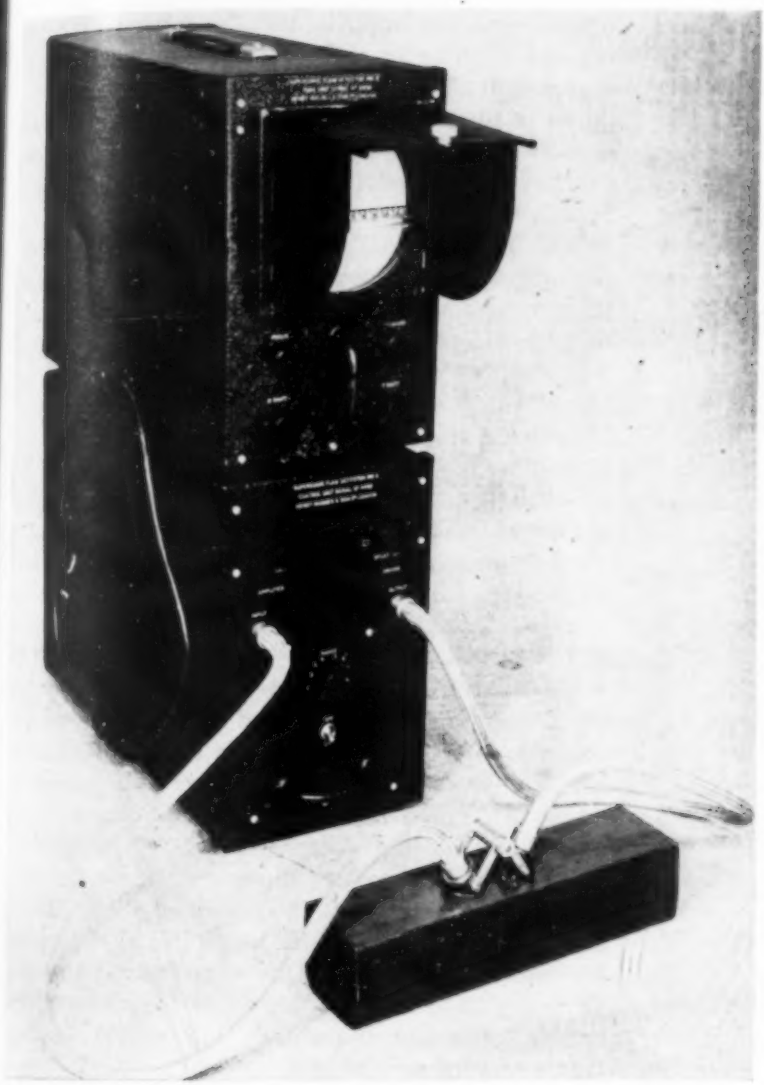


Fig. 4 — Electronic Flaw Detector Made by Henry Hughes & Son, Ltd., London

perpendicular to the center of the quartz flat, and the maximum receiver sensitivity is along the same line. This is indicated by the closer spacing of the lines in Fig. 6. Intensity falls off each side of this maximum at a very slow rate for a few degrees, and then much more rapidly, so that it is zero at about 8° off the axis on either side. (At greater angles from the axis there are a number of other maxima and minima but in searching for flaws which are barely detectable, it is only the main beam that need be considered.)

It is this main beam that is indicated in Fig. 6, and from this figure it is clear that the maximum echo will be received from a given flaw if it is located on the intersection of the axes of the transmitter and the receiver systems. Normal spacing will operate well to distances of 2 in. below the surface, but to detect an echo from a greater distance it will be necessary to use a greater separation of the wedges or, alternatively, to use wedges that incline the beam axis at a smaller angle.

This point is most important for the device illustrated in Fig. 4, and action must be taken accordingly, or the impression may be gained that flaws exist only at a certain distance from the surface, as it may happen that no echoes are received from any other point. Alternatively, the flaws may be missed because they occur at a depth considerably greater than or less than the region of intersection of the beams.

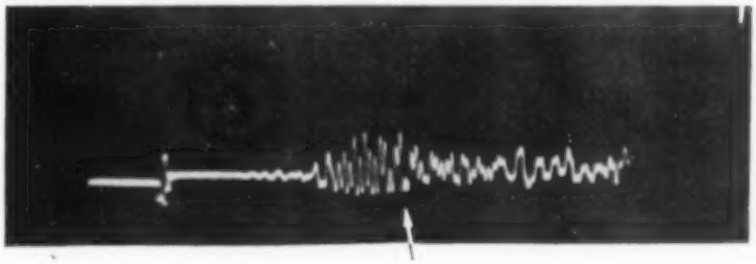
Flaws can be detected in samples with curved surfaces by the use of special fitted adaptors. For round billets the "sensitive area" (Fig. 6) is obviously the axis of the shape, and here is the

Size Limits of Detectable Flaws

It must be emphasized that the flaw shown by Fig. 5 is in the form of an extremely thin crack impossible of detection by the X-ray, for example, and too deep to be shown by magnaflux. "Flakes" in billets and forgings are instances. Cracks have been detected by the supersonic flaw detector that are too small to be seen under the best microscope without first etching the sample. Whereas radiographic detection ordinarily requires that the flaw be a few per cent of the thickness of sample, a supersonic echo can be obtained from a crack less than one-thousandth as thick as this. For example, if gage blocks are wrung together the mutual surface is readily detected.

In interpreting the results, it must be appreciated that the maximum intensity of the supersonic waves is on the axis of the beam, that is, on a line

Fig. 5 — Oscillogram From Badly Flawed Billet; the Bottom Echo Shown in Fig. 1 or 2 Is Not Distinguishable



region where flaws, if present, are most likely to exist.

Supersonic flaw detection is adaptable to the solution of many problems, and has already been applied in Britain to flaw detection in steel, nonferrous metals and plastics. The equipment shown consumes 1 ampere of current at 230 volts, and can be operated from any industrial alternating current lines with voltage between

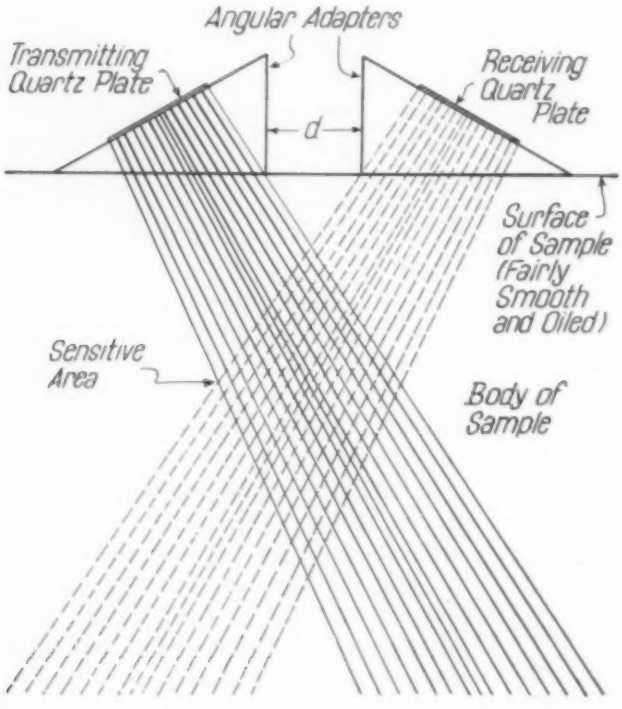


Fig. 6 — Diagram Showing That Beam Has Useful Intensity Within an 8° Cone, and That Angle and Distance d May Be Adjusted to Place the Most Sensitive Area in a Position Where Flaws Are Expected

200 and 250. The equipment consists of two cases or housings, each approximately the size of a small suitcase for traveling, and can easily be carried by one man or trundled around. Setting up requires only a few minutes.

Editor's Addendum

Detection of internal defects by supersonic waves is a subject that has been restricted by the American censor for reasons of military security, although the equipment has been used in production and certain aspects of its operation described publicly — for example by Prof. Firestone, author of the preceding article, at a round-table discussion on instruments for quality control held at the last general convention of the ASM in Cleveland (October 1944). The British instrument described in Mr. Simons's article uses two quartz plates, one to send the impulse and the other to receive the echo. The impulse is like the blink of a searchlight; its duration is very short as compared to the time it is dark. The sending crystal is active for, say, a millionth of a second and then inactive for a sixtieth of a second. There is no reason why the sending crystal should not also act as a receiving crystal during these inactive periods, if the echoes die away before the next impuse is sent out, and that is, in fact, the way the American equipment is designed to operate.

Suppose, then, a 4-in. square billet was being inspected. One oiled surface could be scanned by moving the crystal over its face. (The work, of course, could be inspected while immersed in an oil bath.) As long as the oscilloscope screen shows an undisturbed line (up to the position of the bottom echo, as shown in Fig. 1 of this article) the material is sound. As soon as there are any wiggles in this line it is an indication of a flaw in the metal.

Industrially, the equipment will probably be of most value in discovering defects of very small thickness, yet of considerable extent laterally. The most important of these is the so-called "flake", a crack whose walls are pressed close together, and therefore incapable of being discovered by an X-ray exposure except in the unlikely chance that it is exactly edge-on. Other damaging defects are the longitudinal seams or laminations in plates. One can forecast the use of supersonic reflectoscopes or flaw detectors in verifying the soundness and extent of lap welds or spot welds.

A so-called "Sonigage" has been described in *Steel* for March 5, 1945, by Wesley S. Erwin of research laboratories division of General Motors Corp. It is designed to measure the thickness of metal parts when only one surface is accessible — as occurs in piping or in hollow propeller blades. It is contained in a cabinet about the size of a portable radio set. The equipment generates currents of high frequency; these frequencies are varied by merely turning a knob, and supersonic waves are continually emitted by a quartz plate held against the sheet to be measured. The *time* it takes the echo to return is a measure of the thickness traveled, as in the early depth gage for measuring ocean depths, but this equipment picks out the frequency that sets the sheet into resonant vibration — a matter directly related to its thickness. The pointer on a small power-output meter indicates the resonant frequency, as it is approached from either above or below, in much the same way that a "magic eye" is used to tune the ordinary radio receiver on a favorite station.

Correspondence

Tool Life Versus Metal Cut

TOLEDO, OHIO

To the Readers of METAL PROGRESS:

The tool engineer finds the standard Taylor curves very valuable, since he desires to know the relationship between cutting speed and tool life when machining a given material. The metallurgist usually meets the problem in a different form. He is confronted with the effect of changes in the material where the machining set-up is unaltered. A typical example would be a large mass production operation for machining a steel having a machinability rating of 60. A balance, based upon normal tool life, is established between the tool grind, set-up operations, machine repair, and the actual operation of the machine tools.

The metallurgist is responsible for supplying steel of the proper structure and hardness to give long tool life in this operation. When he does not, the whole set-up gets out of balance. Tool life drops, tool grind works overtime, tool changes and adjustments cause production to drop. To anticipate and prevent such conditions, we have used a chart that shows directly the relationship between the percentage of normal tool life and the machinability of the metal cut.

Such a chart is shown in the data sheet on page 504-B. Taylor's law, $Vt^n = C$, has been plotted so as to express C, the machinability rating, in the range from 30 to 100 on the abcissa, and t, the tool life, in the range from 5% to 10,000% of normal on the ordinate. The curves on the chart show this relationship in terms of tooling set-up for various machinability ratings.

For example, a tooling set-up is established for a machinability rating of 60. The metal being cut also has a rating of 60 and its plot is shown at *A*, indicating a tool life 100% of normal. If, however, the rating of the metal cut drops to 50, as shown at Point *B*, the tool life drops to 27% of normal. On the other hand, if the machinability of the metal cut rises to 70, as shown at Point *C*, then the tool life rises to 300% of normal.

A chart of this type is subject to all the limitations of expressing the machinability of a material in terms of a single number. In drawing the curves it has been assumed that the exponent *n* in the Taylor law is always 0.14. This is not always true, for values between 0.100 and 0.2000 are found in the literature. Generally, however, for the average type of tools and machining operation, the chart will give a good approximation to the effect of changes in the material on the tool life, when the machining set-up is held constant.

NELSON G. MEAGLEY
Metallurgical Dept.
Willys-Overland Motors, Inc.

Engineering Properties of "A" Nickel

NEW YORK CITY

To the Readers of METAL PROGRESS:

In this office we are great believers in the possibilities of nickel and its alloys, yet even we were amazed to note in the data sheet in July *Metal Progress* (page 96-B) that the yield strength of "A" Nickel in short-time, high temperature tests is from two to three times the tensile strength. Some of us think this is great stuff if you can really do it!

O. B. J. FRASER
Director of Technical Service
International Nickel Co., Inc.

[EDITOR'S SHAMEFACED NOTE: Column headings were reversed, despite proof reading ("for sense") by three metallurgists!]

Lithium, the Life Saver

LONG ISLAND CITY, N. Y.

To the Readers of METAL PROGRESS:

War uses of the lightest metal, lithium, and its compounds have accelerated production sevenfold as of 1944 over 1929, present annual production being at the rate of about 14,000 tons. Many of the new metallurgical uses are still under secrecy orders; however, one of the non-metallurgical uses of utmost interest can be described. It has to do with air-sea rescue work.

Lithium hydride releases free hydrogen when in contact with water. On this simple chemical property of lithium have been based techniques

which have been responsible for saving the lives of numerous pilots and crew members downed at sea in combat areas.

It is lithium's lightness which makes it so valuable. A conventional metal cylinder holds 235 cu.ft. of hydrogen under pressure. This cylinder weighs 137 lb. The same volume of hydrogen can be generated from 4.85 lb. of lithium hydride, which occupies a space of less than 0.1 cu.ft. And two 1-lb. cans of lithium hydride are all that is needed for this role.

All armed services now equip planes which must fly over water with rubber life rafts. The raft has a radio set which sends out automatic radio signals on the S.O.S. frequency by merely turning a crank. But to enable the signals to travel up to 400 miles, an aerial is necessary. This aerial is a 300-ft. copper wire. The wire must be lifted into the air. To accomplish this, a balloon is attached, and the balloon must be inflated.

It would be impractical to use a cylinder of gas for this, so lithium hydride is carried in a 1-lb. can. One canful suffices; another is carried as a safety margin.

The flier on the raft simply opens the can, attaches a nozzle to the balloon, holds the can in the water, and hydrogen pours forth into the balloon.

HANS OSBORG
Vice-President
Lithaloys Corp.

Prefabricated Houses of Aluminum

NEW YORK CITY

To the Readers of METAL PROGRESS:

Rebuilding houses for bombed-out English civilians is one of the pressing needs, since about 200,000 have been entirely destroyed and 250,000 rendered uninhabitable by enemy action. (A further 4 million were damaged, and this grand total of 4½ million damaged or destroyed homes is over one-fourth of the British houses standing in 1939.) Lack of building material and labor has required the utmost economy, not only in repairs but in the construction of entirely new buildings. This has naturally led to the prefabricated house, of which 145,000 are being erected on an urgent schedule.

First among the prefabricated dwellings was the famous "Portal house", containing living room, kitchen, two bedrooms, bathroom, lavatory and shed — all contained in an area of 616 sq.ft. within the outer walls.

The United States is supplying 30,000 houses of another design, deliveries to be completed by the end of 1945. This is a timber framed structure, about 24x28 ft. in ground area, a single-story building with a flat roof, no basement, containing a living room, two bedrooms, kitchen and bathroom. A built-in larder, with louvers for ventilation from the outside, will serve in place of a refrigerator or ice box. Plumbing and fixtures will be shipped with the structure, while wiring, heating and other equipment will be installed in Britain.

Among the newer types of houses is the "Airoh" aluminum house, designed by Aircraft Industries Research Organization on Housing. An order for 50,000 of these has been placed with various firms prominent in the manufacture of aircraft. By far the most highly prefabricated type yet produced, the Airoh is made in four sections, each complete in itself. The sections are coupled by interlocking fastenings and the services are joined up within a few hours. The size of each section (22 ft. 5½ in. long, 10 ft.

One of Four Sections of Prefabricated Aluminum House (Kitchen and Living Room) Being Lifted From Trailer to Foundation at Site

8½ in. high and 7 ft. 6 in. wide) was determined by balancing speed of construction and minimum consumption of man-hours on the site, with the requirements of transport.

The floor frame is made in aluminum alloy, faced with normal wooden floor boards. The walls are faced externally with alloy sheet painted with a rough cast finish of stone appearance; internally with plaster board, spray-painted in color. The wall filling is a light weight aerated cement which has a high insulation value. The roof is formed of six trusses and two trussed purlins, covered with aluminum alloy sheet, the latter being packed internally with cork, which gives thermal insulation and eliminates drumming. The trusses are made of extruded sections, and are bolted to walls and central partition. The roof sheathing is 18-gage, corrugated with ribs on 4½-in. centers. Joints are made at edges, where the sheet is flanged upward, by covering with a sealing strip with capillary groove.

There is a high standard of thermal and sound insulation throughout — both in the exterior structure and internal partition. In these respects the structure should be better than the standard 9-in. brick wall, and the roof better than tiles and roof felt. Chief advantages of aluminum alloys for prefabricated house construction, of course, are their light weight for transport and handling, and their permanence.

It is estimated that the aluminum house will cost about £900 ($3600), while the Portal house and the American timber-frame are priced between £600 and £800 ($2400 and $3200). About $400 worth of fittings, such as cupboards, stove and refrigerator, will go with each house. Where the materials interfere with radio reception, a special aerial will be supplied.

JOAN LITTLEFIELD
British Information Service

Antiseptic Cutting Oils

YORK, PA.

To the Readers of METAL PROGRESS:

The article in "Bits and Pieces" in the May issue, regarding skin infections from the handling of oils, is good as far as it goes. But it should be pointed out that oil even when manufactured with aseptic precautions, sterilized or free from germs, may still cause an irritation of the skin which prepares the way for infection from other sources. In other words, clean oil is a good thing but *not* a remedy.

As a research engineer, the writer has experienced three severe cases of dermatitis after working with *clean* oil. In the first case, the company sent him to a specialist and at the end of three weeks he was still incapacitated — even worse than on the first day. Then, on the advice of an old German who constantly worked with oil, he bathed the affected parts with a thick lather of Parke, Davis & Co.'s germicidal soap called Neko and *did not wash it off*. In two days the trouble cleared up.

In the second case, years later, the company again sent him to a specialist who tried violet rays and other modern ideas with no success, but refused to try the above remedy. After three weeks the writer disobeyed orders, used the soap and again was soon cured. In the third case, it is useless to say that he refused to go to a specialist and be told to change his occupation so as to avoid contact with oil!

M. R. WELLS

Maximum Carbon in Carburized Cases

COLUMBUS, OHIO

To the Readers of METAL PROGRESS:

Mr. Breitbart, in his article on "Maximum Carbon in Carburized Cases" in the June 1945 issue, has presented a very interesting aspect of a carburizing problem that has been the subject of discussion for a number of years. His tests were well chosen and developed. However, it is possible that his theory of massive carbide formation is unnecessarily restricted by the very great significance which he attaches to the prior presence of carbide nuclei.

Theoretically, there are three essential factors which determine whether or not massive carbides will be present at the end of the carburizing cycle. First, if the carburizing potential is sufficiently high, austenite supersaturated with carbon may be formed at the carburizer-steel interface. The supersaturated austenite will immediately start to decompose (precipitate carbide). Thus massive carbides might be formed in the absence of any prior nuclei. It is true that Mr. Breitbart found no evidence to support this view, but it is also true that only two liquid and one gaseous carburizing media were used. There is no reason to believe that some other medium might not furnish a higher carburizing potential.

Second, the alloy elements present in the steel determine the energy level of the carbon in the carbides formed during carburizing. There is ample qualitative evidence that chromium carbide, for example, is more stable than simple iron carbide. This may be interpreted as meaning that the energy level of carbon in the form of chromium carbide is lower than the energy level

of carbon in the form of iron carbide. Therefore, all other things being equal, a lower carburizing potential will be required to produce massive carbides in a chromium steel than will be required for the formation of massive carbides in a plain carbon steel. The photomicrographs showing more massive carbides to be present in the S.A.E. 6152 steel (his Fig. 6) than were present in the plain carbon tool steel (his Fig. 8), confirm this — as indeed Mr. Breitbart does, at least in substance, in the article.

Third, the energy required for carbide nuclei formation will in some instances determine whether massive carbides will be present after carburizing. It is with respect to this factor that Breitbart's data are particularly illuminating. The energy for nucleation of most precipitation reactions is generally considered to be quite small. For example, the difference between the A_{cm} point obtained after very slow heating and after very slow cooling may be regarded as a crude measurement of the energy required for carbide nucleation. Since, even with finite cooling rates, the A_{cm} temperature obtained on cooling approaches within a few degrees the A_{cm} temperature on heating, the carbide nucleation energy must be small. Though this nucleation energy is small, it may be quite significant, should it develop that carburizing potentials of various carburizing media all fall within a narrow range or are limited by a certain critical maximum. For this reason, it would be highly desirable to employ a wide variety of carburizers in another series of similar tests. Such tests would determine which of the three factors are of purely theoretical concern, and which of them are of practical as well as theoretical importance.

G. K. MANNING
Assistant Supervisor
Battelle Memorial Institute

Ghost

"The Old Man of the Mountain", Found in the White Cast Iron Examined at 150 Diameters by Charles R. Wilks, Assistant Metallurgist, American Brake Shoe Co., Mahwah, N. J.

Measuring Liquid Steel's Temperature

LONDON, ENGLAND

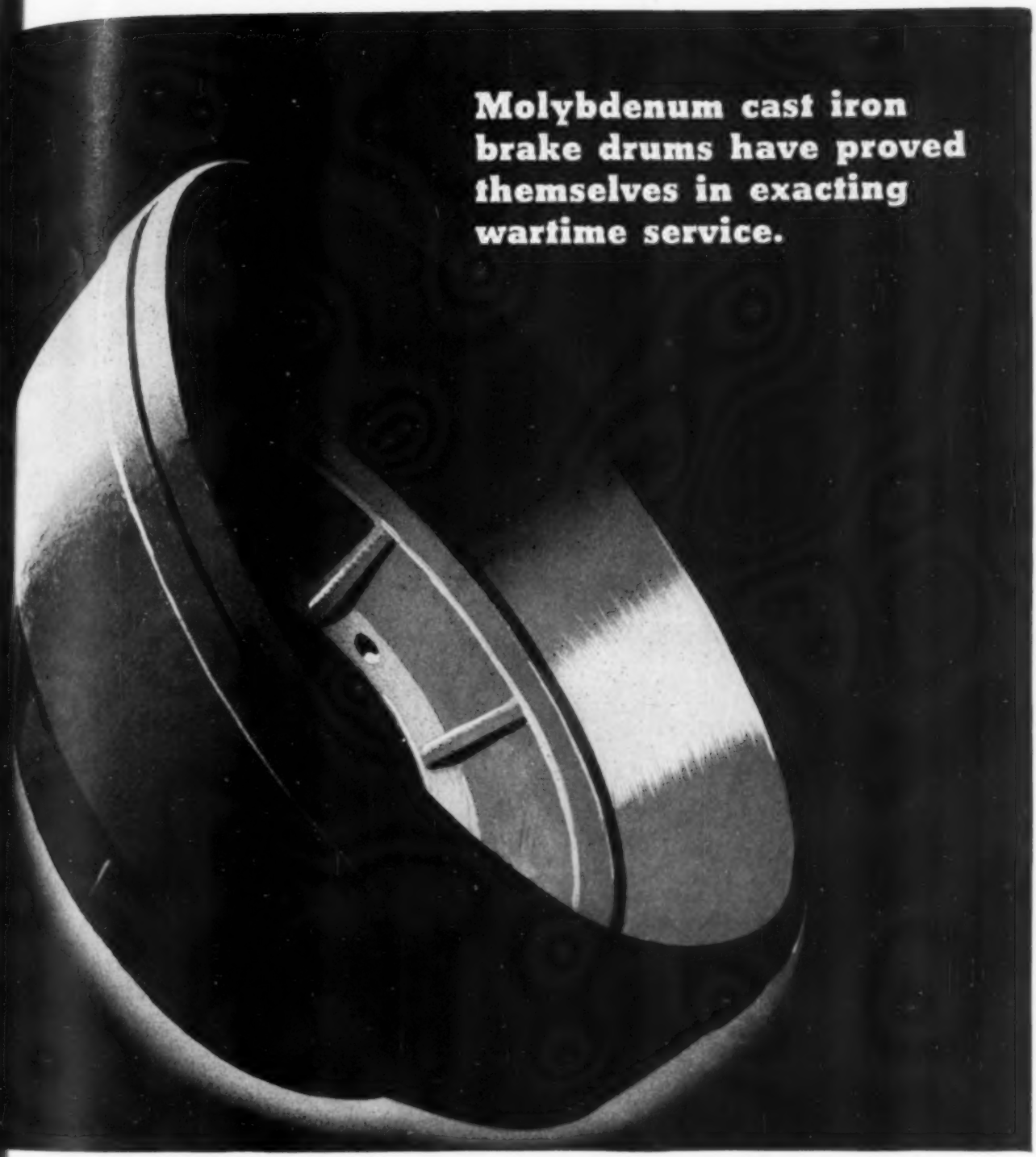
To the Readers of METAL PROGRESS:

In the January 1945 issue, Mr. Emerick of Jones & Laughlin Steel Corp. states that the preferred method of getting the temperature of a steel bath is by thrusting an open-end tube into it, equipped at its cool end with a radiation-sensitive device. Later (June 1945) the Editor in "Critical Points" notes with approval what appeared to him as a new use of a short platinum thermocouple, protected with a thin silica tube mounted at the end of a long pipe handle, and immersed into the bath.

It may not be presumptuous to call your attention to the fact that the temperature measurement of liquid steel has been regarded in this country for several years as a problem for which at least one completely satisfactory method has been developed and is now generally used. I refer to the methods — similar to the one described by your Editor — developed by Messrs. Schofield and Grace and described in several publications by the Iron & Steel Institute. This method, used in connection with ink recorders and giant indicators, has been introduced in practically all the big steelworks in this country and in many small ones as well. The method and the equipment used are so simple that it can be used even in works where there is hardly any staff trained in dealing with instruments.

This does not mean that due attention has not been paid to the alternative method of using radiation instruments, and a great deal of experimental work has been done in this direction. It seems that there is not a great deal of difference in the service costs of the two types of equipment, but platinum thermocouples have a definite advantage in that they do not have to be rechecked at comparatively frequent intervals, as is necessary for all radiation-sensitive devices, especially photocells. Furthermore, thermocouples stand up to a great deal more rough handling. Lastly, if the *steel's* temperature is to be measured, rather than that of the slag or the furnace roof, the immersion thermocouple is the obvious and direct method. Slag may be from 20 to 100° F. hotter than the steel.

D. C. GALL
Tinsley (Industrial Instruments) Ltd.



AMAX FURNISHES AUTHORITATIVE ENGINEERING DATA ON MOLYBDENUM APPLICATIONS.

ARMY E NAVY

MOLYBDIC OXIDE, BRIQUETTED OR CANNED • FERROMOLYBDENUM • "CALCIUM MOLYBDATE"

Climax Molybdenum Company

500 Fifth Avenue • New York City

MOLY

Personals

JAMES C. PATTON, JR., sales engineer in Detroit for Heppenstall Co., has been placed in charge of the company's Chicago sales office.

FRANK H. MULLIGAN has been elected a vice-president of Charles Hardy, Inc., New York, and will also continue as general sales manager of the company.

E. J. HERGENROETHER, recently resigned chief of the Metallurgical Branch of the Steel Division of War Production Board, has resumed his duties with the Development & Research Division of the International Nickel Co., Inc., in charge of automotive steel development, with headquarters in Detroit.

JOHN A. FRASER, formerly special metallurgist for Ford Motor Co., has become chief metallurgical engineer for Commercial Steel Treating Corp., Detroit.

CARL A. BACKER, forme factory manager for the Came Iron Works of Houston, Texas, opened offices in Houston a manufacturers' representative Michigan Tool Co., Colonial Bro Co., Detroit Tap & Tool Co., C nial Bushings, Inc., and Gene Tool Co.

WILLIAM W. AUSTIN, JR., cently in charge of physical chemical testing laboratories Consolidated Vultee Aircraft Co Nashville, Tenn., has accepted position as research metallur on the staff of Southern Resea Institute.

A. W. SIKES has received honorable discharge as lieuten colonel with the Army Grou Forces in the U. S. and Europe theaters, and is now employed product engineer in the Chica headquarters of the Celotex Co

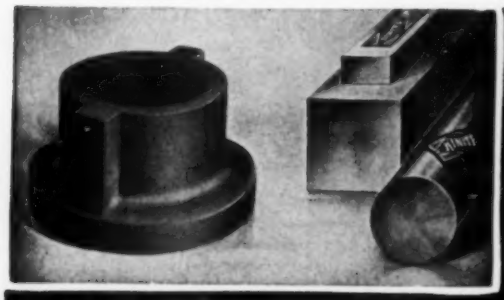
WILLIAM A. DERIDDER been elected president and gene manager of Adel Precision Pr ucts Corp., Burbank, Calif., and w also continue as president of G eral Metals Corp., Vernon, Calif.

JOSEPH B. ENNIS, senior vi president of the American Loco tive Co., has been granted honorary degree of Doctor of En neering by Clarkson College Technology, Potsdam, N. Y.

BERTON H. DELONG, forme chief metallurgist, and PAUL GREENAWALD, formerly gene superintendent, have been pointed directors and vice-pre dents of the Carpenter Steel Reading, Pa.; Mr. DELONG will c tinue to supervise the research development work, and Mr. GREEN WALD will be in full charge of production.

JOHN L. YOUNG, formerl vice-president in charge of ind trial research and development the United Engineering and Fou ry Co., has been elected to newly created post of vice-pre dent in charge of engineering United States Steel's National Tu Co., Pittsburgh.

CHARLES T. GREENIDGE, search metallurgist, Battelle Me rial Institute, Columbus, Ohio, been elected vice-chairman of newly formed Columbus Techni Council.



KINITE

THE STEEL WITHOUT AN EQUAL

KINITE is in the high carbon chrome alloy tool steel air hardening class.

An analysis all of its own . . . .
Its characteristics:

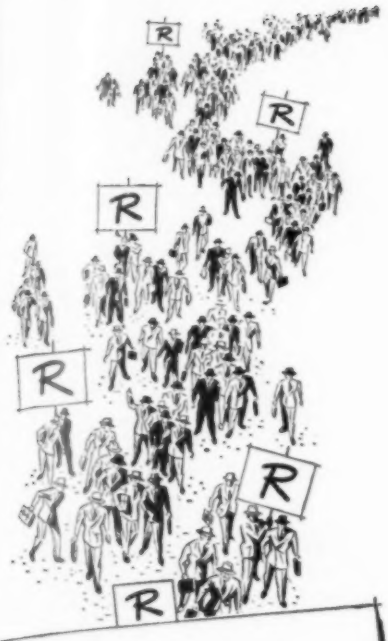
1. Increases production.
2. Reduces grinding and retooling time.
3. Resists wear and abrasion.
4. Excellent machinability.
5. Minimum distortion.
6. Fine heat treatability.
7. Immune to cracking during heat treatment.
8. In bar stock or castings.

KINITE alloy air hardening steel offers an unusual combination of features never before found in a steel of this type.

Pamphlets on request.

EST. BOKER 1837

H. BOKER & CO., Inc.
101 DUANE ST. • NEW YORK



REVERE

—AT YOUR SERVICE

DIVISION OFFICES AND MILLS

BALTIMORE DIVISION
P. O. Box 2075
1301 Wicomico Street
Baltimore 3, Md.
Phone: Gilmor 0222
Teletype: BA 164

MICHIGAN DIVISION
5851 West Jefferson Avenue
Detroit 9, Mich.
Phone: Vinewood 1-7350
Teletype: DE 237

ROME DIVISION
Rome, New York
Phone: Rome 2000
Teletype: ROME N Y 447

MAGNESIUM-ALUMINUM DIVISION
P. O. Box 2075
1301 Wicomico Street
Baltimore 3, Md.
Phone: Gilmor 0222
Teletype: BA 164

DALLAS DIVISION
2200 No. Natchez Avenue
Chicago 35, Ill.
Phone: Merrimac 2600
Teletype: CG 957

NEW BEDFORD DIVISION
24 North Front Street
New Bedford, Mass.
Phone: New Bedford 8-5601
Teletype: NB 87

CHICAGO MANUFACTURING DIVISION
2200 No. Natchez Avenue
Chicago 35, Ill.
Phone: Merrimac 2600
Teletype: CG 957

ROME MANUFACTURING COMPANY DIVISION
Rome, New York
Phone: Rome 2800
Teletype: ROME N Y 449

DISTRICT SALES OFFICES

At above Mill Points and in the following cities

ATLANTA 3, GA.
Rhodes-Haverty Bldg.
Phone: Main 2142
Teletype: AT 96

BOSTON 10, MASS.
140 Federal Street
Phone: Hubbard 7190

BUFFALO 7, N. Y.
1807 Elmwood Avenue
Phone: Delaware 7616

CINCINNATI 2, OHIO
Carew Tower
Phone: Main 0130
Teletype: CI 171

CLEVELAND 15, OHIO
Midland Bldg.
Phone: Cherry 3930
Teletype: CV 572

DALLAS 1, TEXAS
Tower Petroleum Bldg.
Phone: Central 8681
Teletype: DL 88

DAYTON 2, OHIO
Mutual Home Bldg.
Phone: Hemlock 3271

GRAND RAPIDS 2, MICH.
Keeler Building
Phone: Grand Rapids 8-0511 & 6-1314
Teletype: GR 376

HARTFORD 3, CONN.
410 Asylum Street
Phone: Hartford 2-3828
Teletype: HF 87

HOUSTON 2, TEXAS
Mellie Esperson Bldg.
Phone: Fairfax 7932

INDIANAPOLIS 4, IND.
Circle Tower
Phone: Market 1908

LOS ANGELES 15, CALIF.
714 W. Olympic Blvd.
Phone: Richmond 9314

MILWAUKEE 2, WIS.
626 E. Wisconsin Avenue
Phone: Marquette 1440
Teletype: MI 292

MINNEAPOLIS 2, MINN.
Metropolitan Bldg.
Phone: Atlantic 3285

NEW YORK 17, N. Y.
New York Central Bldg.
75 East 45th Street
Phone: MUrray Hill 9-6800
Teletype: NY 1-1222

PHILADELPHIA 3, PA.
Sixteen Sixteen Walnut St. Bldg.
Phones: Bell—Pennypacker 6133
Keystone—Race 1847
Teletype: PH 206

PITTSBURGH 19, PA.
Gulf Bldg.
Phone: Court 4342
Teletype: PG 572

PROVIDENCE 3, R. I.
Industrial Trust Bldg.
Phone: Gaspee 8110

ST. LOUIS 1, MO.
Telephone Bldg.
1010 Pine Street
Phone: Garfield 4416
Teletype: SL 191

SAN FRANCISCO 4, CALIF.
Russ Bldg.
Phone: Sutter 0282

SEATTLE 1, WASH.
1331 Third Avenue
Phone: Main 8372

e full Revere facilities, including the evere Technical Advisory Service, are ade available to you through the ffices listed here.

In addition Revere Distributors in all arts of the country are eager to serve ou.

REVERE

OPPER AND BRASS INCORPORATED

Founded by Paul Revere in 1801

Executive Offices: 230 Park Avenue
New York 17, N.Y.

Listen to The Human Adventure *on the Mutual Network every Wednesday evening; 10 to 10:30 p. m., EWT.*

Personals

WILLIAM R. MANSKE has been appointed works manager of the Denver Plant, Amsco Division of American Brake Shoe Co.

E. K. WATTERS, formerly associated with the Hughes Tool Co., is now with the Texowell Service & Machine Co. as vice-president and general manager.

JOHN M. NALLE has resigned as senior project engineer with the Armstrong Cork Co. to accept a position as chief engineer of Commercial Filters Corp., Boston.

ROY E. SWIFT is now assistant professor of metallurgical engineering for Purdue University.

DAVID F. BEARD has been named manager of advertising and public relations for the Aluminum Division of the Reynolds Metals Co., Louisville, Ky.

LEE H. DEWALD has been appointed a research associate in powder metallurgy at the Massachusetts Institute of Technology.

ROGER H. WEST has been transferred from Chicago district to Pueblo, Colo., and appointed chief inspector of Pueblo Unit Robert W. Hunt Co., at Colorado Fuel & Iron Corp.

F. E. MCATEE, formerly assistant superintendent of the Birmingham, Ala., shop of Chicago Bridge & Iron Co., is now welding engineer for the company with headquarters in Chicago.

RALPH W. JENNINGS, formerly chemist for Aero Products Division of General Motors Corp., Dayton, Ohio, is now research engineer U. S. Maritime Commission, Washington, D. C.

MERVIN L. REYNOLDS, metallurgist of Henderson Foundry & Machine Co., has resigned to accept a position with the Bearing Division of P. R. Mallory, Inc.

GEORGE E. SEELEY, formerly budget manager for the Stanley Works, Bridgeport, Conn., is now research engineer for Johnson Steel & Wire Co., Inc., Worcester, Mass.

CURT LOESER has been appointed Wisconsin representative for American Gas Furnace Co.

CARL B. MCLAUGHLIN, formerly associated with the Pittsburgh office of Tube Turns, Inc., is now heading up the recently established engineering service division of Tube Turns in Louisville, Ky.

Promoted by Mackintosh-Hemphill Co., Pittsburgh: WILLIAM J. MCMILLEN, from assistant manager to manager of roll sales.

E. P. PEARSALL, formerly editor-in-chief of employee publications at Wilmington, Del., has been made assistant advertising manager of the Dravo Corp., Pittsburgh.

CHARLES G. SCHMITT is now sales promotion manager in the eastern territory for the Ziv Steel & Wire Co.

C. K. KENYON of Sheffield Steel Corp. and C. CHILSON of Pratt & Whitney Aircraft Corp., have been appointed to the newly organized Technical Societies Council of Kansas City.

Send for it Today!

ARMY (E) NAVY

You Need This:

Just off the press—this 44-page bulletin is a real contribution to engineering literature and should be in your files. It is an authoritative, well-illustrated treatise which makes clear (a) the mechanics of operation of dynamic adsorptive dehydrators (b) the characteristics which make solid adsorptive dessicants so efficient for the dehydration of air or gases, the drying of liquids, and for industrial control.

A wide variety of both standard and special units is also shown to illustrate how KEMP Dynamic Dryers can be profitably applied to your operations and processes.

THE C. M. KEMP MFG. CO.
405 E. Oliver Street, Baltimore 2, Md.

Please send me copy of new Catalog No. 25-D.

Name ..... Title .....

Company .....

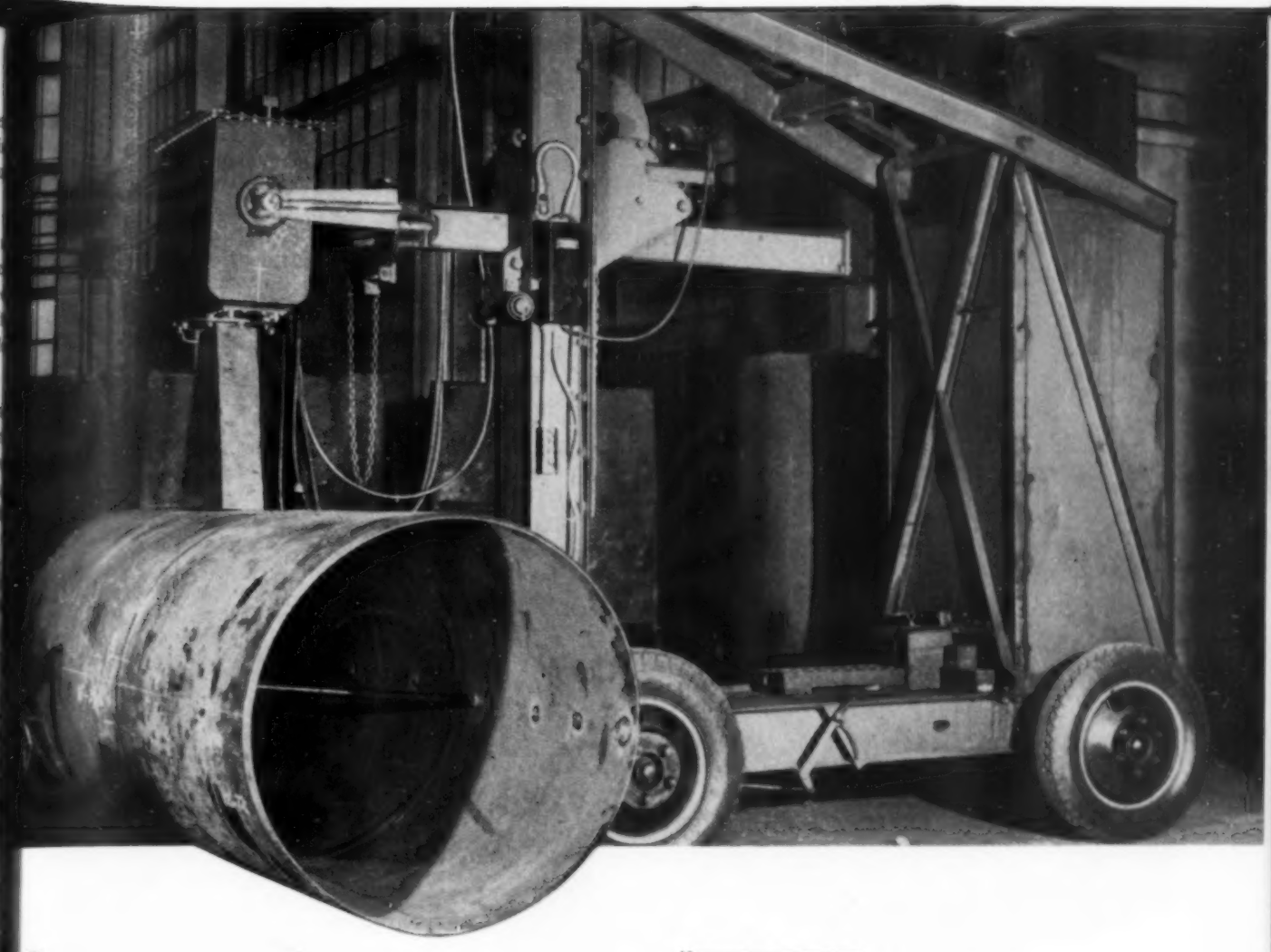
Street ..... City ..... State .....

KEMP PRODUCTS

Dynamic Dryers (adsorptive dehydrators) — Flame Arrestors for vapor lines, flares, etc.
Nitrogen Generators • Inert Gas Producers — The Industrial Carburetor for premixing gases
Atmos-Gas Producers • Immersion Heaters — Submerged Combustion Burners
A complete line of Industrial Burners, and Fire Checks.

Address The C. M. Kemp Mfg. Co., 405 E. Oliver St., Baltimore 2, Maryland

KEMP of BALTIMORE



Q. Which x-ray film for critical examination of 1" welds at 220 kilovolts?

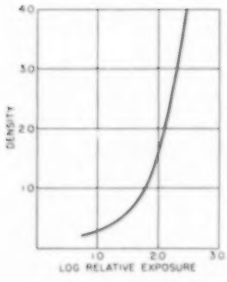
A. Kodak's Type A

FIRST CHOICE in this case—as in many others—the excellent detail and high contrast of Kodak Industrial X-ray Film, Type A, used with lead screens, make its selection sound radiographic practice. In practical examination, Type A's fine grain and high speed help determine the condition of the weld . . .

State of fusion, freedom from harmful slag, inclusions, cracks, porosity—all these are clearly determined . . . with Type A.

Type A's speed also assures fullest possible use of available kilovoltages in meeting a wide range of requirements.

EASTMAN KODAK COMPANY, Rochester 4, N. Y.



Characteristic Curve, Kodak Industrial X-ray Film, Type A: with direct x-ray exposure or with metallic screens.

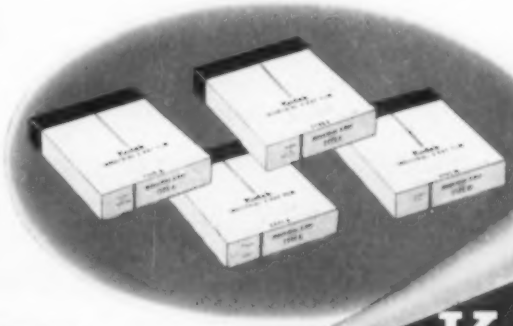
Development: 8 minutes, at 68° F, in Kodak X-ray Developer, or Kodak Liquid X-ray Developer.

Kodak also offers these 3 additional important types of industrial x-ray film

Kodak Industrial X-ray Film, Type K . . . primarily meant for gamma and x-ray radiography of heavy steel parts, or of lighter parts at low x-ray voltages where high film speed is needed.

Kodak Industrial X-ray Film, Type F . . . primarily for radiography, with calcium tungstate screens, of heavy steel parts. The fastest possible radiographic procedure.

Kodak Industrial X-ray Film, Type M . . . first choice for critical inspection of light alloys, or with million-volt radiography, of thinner steel and heavy alloy parts.



. . . the FILM tells the story

Kodak

Personals

WILLIAM R. MANSKE has been appointed works manager of the Denver Plant, Amsco Division of American Brake Shoe Co.

E. K. WATTERS, formerly associated with the Hughes Tool Co., is now with the Texowell Service & Machine Co. as vice-president and general manager.

JOHN M. NALLE has resigned as senior project engineer with the Armstrong Cork Co. to accept a position as chief engineer of Commercial Filters Corp., Boston.

ROY E. SWIFT is now assistant professor of metallurgical engineering for Purdue University.

DAVID F. BEARD has been named manager of advertising and public relations for the Aluminum Division of the Reynolds Metals Co., Louisville, Ky.

LEE H. DEWALD has been appointed a research associate in powder metallurgy at the Massachusetts Institute of Technology.

ROGER H. WEST has been transferred from Chicago district to Pueblo, Colo., and appointed chief inspector of Pueblo Unit, Robert W. Hunt Co., at Colorado Fuel & Iron Corp.

F. E. MCATEE, formerly assistant superintendent of the Birmingham, Ala., shop of Chicago Bridge & Iron Co., is now welding engineer for the company with headquarters in Chicago.

RALPH W. JENNINGS, formerly chemist for Aero Products Division of General Motors Corp., Dayton, Ohio, is now research engineer, U. S. Maritime Commission, Washington, D. C.

MERVIN L. REYNOLDS, metallurgist of Henderson Foundry & Machine Co., has resigned to accept a position with the Bearing Division of P. R. Mallory, Inc.

GEORGE E. SEELEY, formerly budget manager for the Stanley Works, Bridgeport, Conn., is now research engineer for Johnson Steel & Wire Co., Inc., Worcester, Mass.

CURT LOESER has been appointed Wisconsin representative for American Gas Furnace Co.

CARL B. MCLAUGHLIN, formerly associated with the Pittsburgh office of Tube Turns, Inc., is now heading up the recently established engineering service division of Tube Turns in Louisville, Ky.

Promoted by Mackintosh-Hemphill Co., Pittsburgh: WILLIAM J. MCMILLEN, from assistant manager to manager of roll sales.

E. P. PEARSALL, formerly editor-in-chief of employee publications at Wilmington, Del., has been made assistant advertising manager of the Dravo Corp., Pittsburgh.

CHARLES G. SCHMITT is now sales promotion manager in the eastern territory for the Ziv Steel & Wire Co.

C. K. KENYON of Sheffield Steel Corp. and C. CHILSON of Pratt & Whitney Aircraft Corp. have been appointed to the newly organized Technical Societies Council of Kansas City.

Send for it Today!

ARMY (E) NAVY

You Need This:

Just off the press—this 44-page bulletin is a real contribution to engineering literature and should be in your files. It is an authoritative, well-illustrated treatise which makes clear (a) the mechanics of operation of dynamic adsorptive dehydrators (b) the characteristics which make solid adsorptive dessicants so efficient for the dehydration of air or gases, the drying of liquids, and for industrial control.

A wide variety of both standard and special units is also shown to illustrate how KEMP Dynamic Dryers can be profitably applied to your operations and processes.

THE C. M. KEMP MFG. CO.
405 E. Oliver Street, Baltimore 2, Md.

Please send me copy of new Catalog No. 25-D.

Name ..... Title .....

Company .....

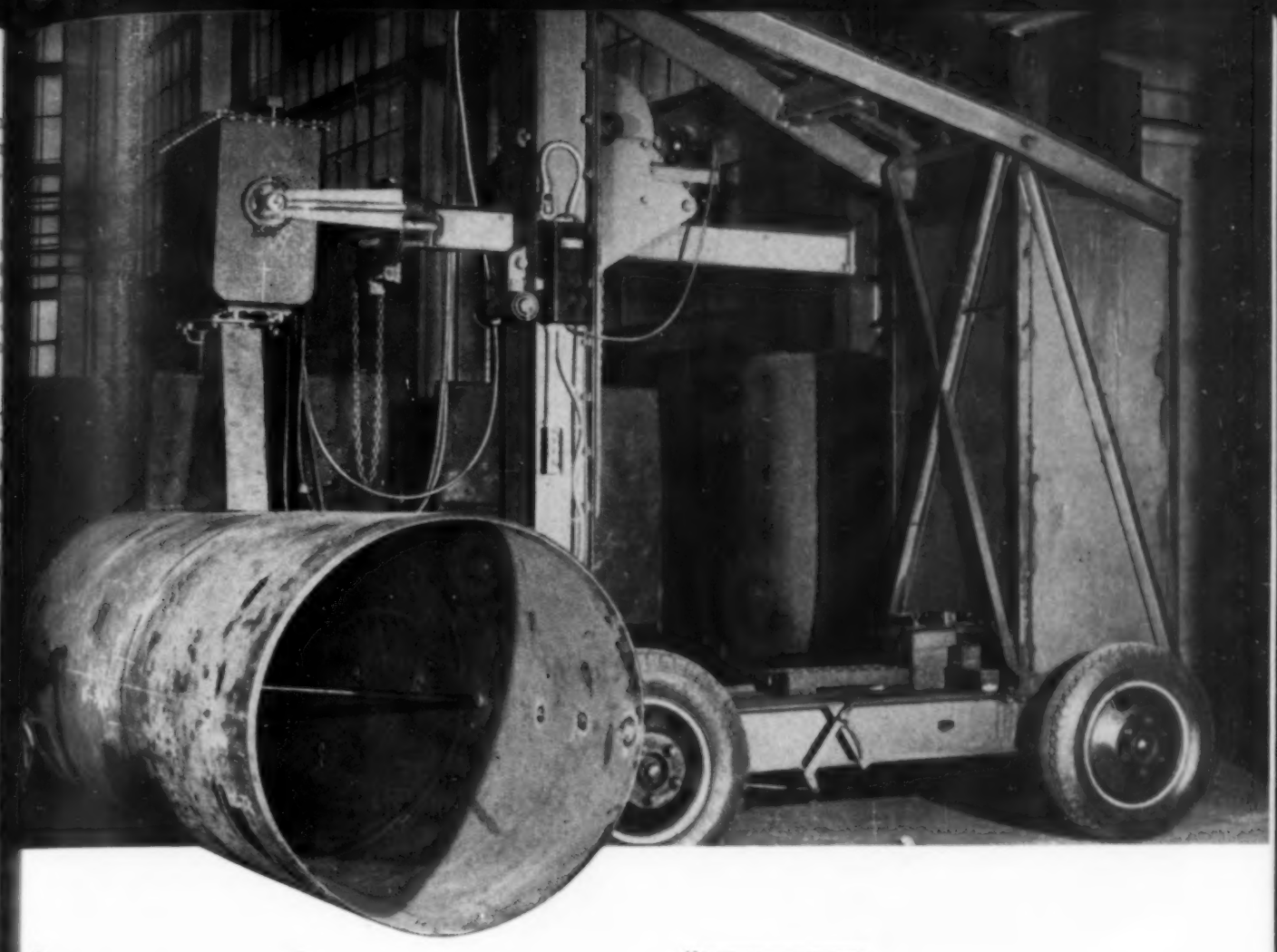
Street ..... City ..... State .....

KEMP PRODUCTS

Dynamic Dryers (adsorptive dehydrators) — Flame Arrestors for vapor lines, flares, etc.
Nitrogen Generators • Inert Gas Producers — The Industrial Carburetor for premixing gases
Atmos-Gas Producers • Immersion Heaters — Submerged Combustion Burners
A complete line of Industrial Burners, and Fire Checks.

Address The C. M. Kemp Mfg. Co., 405 E. Oliver St., Baltimore 2, Maryland

KEMP of BALTIMORE



Q. Which x-ray film for critical examination of 1" welds at 220 kilovolts?

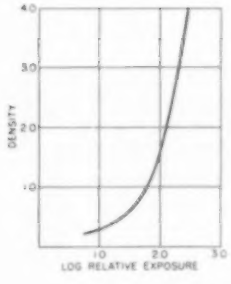
A. Kodak's Type A

FIRST CHOICE in this case—as in many others—the excellent detail and high contrast of Kodak Industrial X-ray Film, Type A, used with lead screens, make its selection sound radiographic practice. In practical examination, Type A's fine grain and high speed help determine the condition of the weld . . .

State of fusion, freedom from harmful slag, inclusions, cracks, porosity—all these are clearly determined . . . with Type A.

Type A's speed also assures fullest possible use of available kilovoltages in meeting a wide range of requirements.

EASTMAN KODAK COMPANY, Rochester 4, N. Y.



Characteristic Curve, Kodak Industrial X-ray Film, Type A: with direct x-ray exposure or with metallic screens.

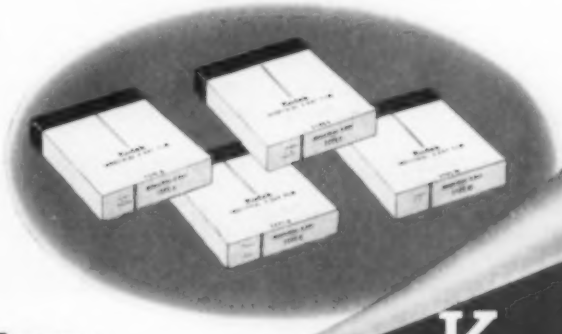
Development: 8 minutes, at 68° F, in Kodak X-ray Developer, or Kodak Liquid X-ray Developer.

Kodak also offers these 3 additional important types of industrial x-ray film

Kodak Industrial X-ray Film, Type K . . . primarily meant for gamma and x-ray radiography of heavy steel parts, or of lighter parts at low x-ray voltages where high film speed is needed.

Kodak Industrial X-ray Film, Type F . . . primarily for radiography, with calcium tungstate screens, of heavy steel parts. The fastest possible radiographic procedure.

Kodak Industrial X-ray Film, Type M . . . first choice for critical inspection of light alloys, or with million-volt radiography, of thinner steel and heavy alloy parts.



. . . the FILM tells the story

Kodak

Gas Turbine

(Cont. from p. 488) position into a cradle so mounted as to rotate the assembly at welding speed. Thin insulating sheets were placed between the various disks to guard the blading and disks from weld spatter, and welding was carried out to a very set sequence laid out on a calendar and checked off as each weld was made. (See Fig. 5.) When welding was finished the rotor was placed on centers and surrounded in a furnace in which it could be rotated at a slow speed and heated slowly and uniformly to 1400° F. This temperature was maintained for 16 hr. and the rotor then allowed to cool. Some rough machining was then done on the rotor before it was returned to the furnace for a process known as heat indication.

It has been found that rotors, operating at high temperatures, will sometimes bend, yet straighten out when cool. This means that a rotor, in perfect balance when cold, will not be in balance at high temperature. To eliminate this possibility the rotor is heat indicated — that is, placed in a furnace with the temperature increasing gradually while the rotor is being rotated. As the temperature is increased the amount that the rotor bends is gaged by measuring the eccentricity, with dial gages, placed outside the furnace, but operating through fingers extending through the furnace wall in contact with the rotor's circumference.

When the rotor reaches a point at which there is no increase in bending with increase in temperature, it is considered to have been "heat indicated" and set in a stable condition, and thereafter it will not bend when the temperature is changed. After heat indication the stub shafts of the rotor are finish-machined, and the rotor is ready for installation in the turbine.

I have described only a few of the manufacturing problems encountered in building equipment to operate at exceedingly high temperatures. As the temperatures at which gas turbines are to be operated increase, these problems will become more difficult. However, it is felt that the biggest gap to be bridged has been the building of the first machine; and that the experience gained can be carried over, with slight modifications, into the building of future gas turbine power plants.

Future Possibilities

One would be rash to make many predictions based on the successful construction of a 2500-hp. turbine plant for ship propulsion. It is fairly certain that units of larger capacity — say 10,000 hp. — are practical, although very large ones and very small ones seem to be machines of the more distant future. The present 2500-hp. plant has an overall efficiency of 29%, which falls in the range between the best small up-to-date steam plant (26%) and the diesel engine (33%). The present plant weighs about 30 lb. per hp., and occupies a space of 3½ cu.ft. per hp. It is designed to burn high grade fuel oil, but eventually "Bunker C" oil may prove practical. One difficulty is that the gas turbine cannot be reversed — reversal must be done by the drive arrangement.

What with the intensive work being done on high temperature alloys by the aeronautical industry, it is certain that operating temperatures can be increased 100° F., with a resulting thermal efficiency of 32 to 34%.

All types of high-speed steel cutting tools are hardened quickly and correctly by the *SENTRY DIAMOND BLOCK METHOD OF ATMOSPHERIC CONTROL.* The Diamond Block inside the furnace, combines with air to generate a rich, protective gas. This automatic, accurate atmospheric control assures uniform hardening, even by unskilled hands. *No regulating. No Adjustment.* Model "Y" Furnaces heat to 2350°F in an hour. Ample Tool size capacities.

Clean — Quiet — Reliable — Safe

- **LOW COST**
- **NO DECARBURIZATION**
- **NO SOFT SKIN**
- **SCALE-FREE**
- **MAXIMUM HARDNESS**
- **TRUE TO SIZE**

Send samples for demonstration or write for Bulletin 1024-1A2

Sentry

The Sentry Company

FOXBORO, MASS., U. S. A.

Leak Proof Gasoline Cans Seam Welded in Seconds

(Photograph Courtesy Noblitt-Sparks Industries)

"Sewing" the sides of this gasoline tank takes only a few seconds, using Mallory Seam Welding Wheels. In less time than it takes to describe the operation, a sturdy, liquid-tight welded container for gasoline is fabricated.

Two factors help assure accurate high-speed production. One is the cooling of both wheel and weld by running water throughout the welding operation. The other plus factor is that seam welding wheels are made of Mallory 3* an alloy with high electrical conductivity and excellent wear resistance. *Results:* strong, clean welds; minimum down time for dressing the welding surfaces; and long electrode life.

Industries, fabricating both ferrous and non-ferrous metals, depend upon Mallory for *superior electrode materials*, including Elkaloy* A, Mallory 3* Metal and Elkonite*. Today they are using many thousands of Mallory standard spot welding tips and holders, in addition to seam welding wheels, flash, butt and projection welding dies for specific applications. Mallory pioneering is helping to win new friends for resistance welding as a technique for high speed production.

Write today for help on your specific resistance welding problems. Ask for your free copy of the latest catalog on Mallory electrodes.

A "Must" for Welding Engineers

You need the improved, revised, expanded Mallory Resistance Welding Data Book (3rd Edition), containing useful information on resistance welding methods, machines and materials. Free to those using resistance welding, when requested on company letterhead. Price to students, libraries and educational institutions: $2.50 per copy, postpaid. Board covers, 8½" x 11", 160 pages.

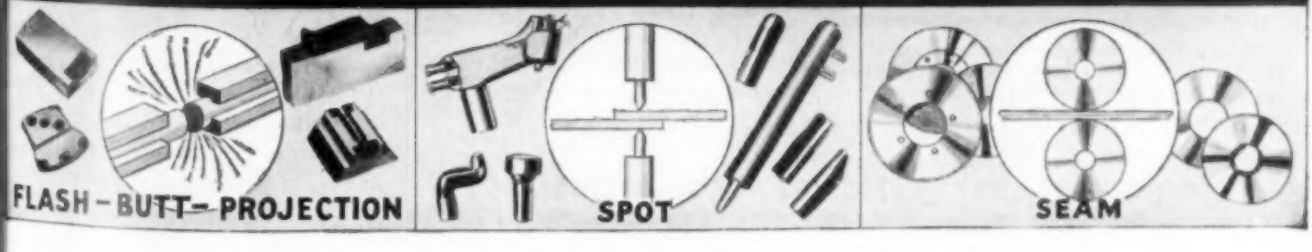
*Reg. U. S. Pat. Off.

P. R. MALLORY & CO., Inc., INDIANAPOLIS 6, INDIANA

In the United Kingdom, Made and Sold by Mallory Metallurgical Products, Ltd., London.

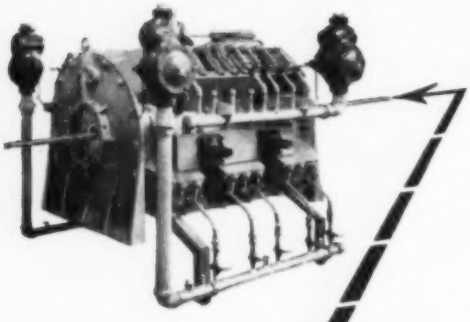
P. R. MALLORY & CO. Inc

MALLORY *Standard Resistance Welding Electrodes*

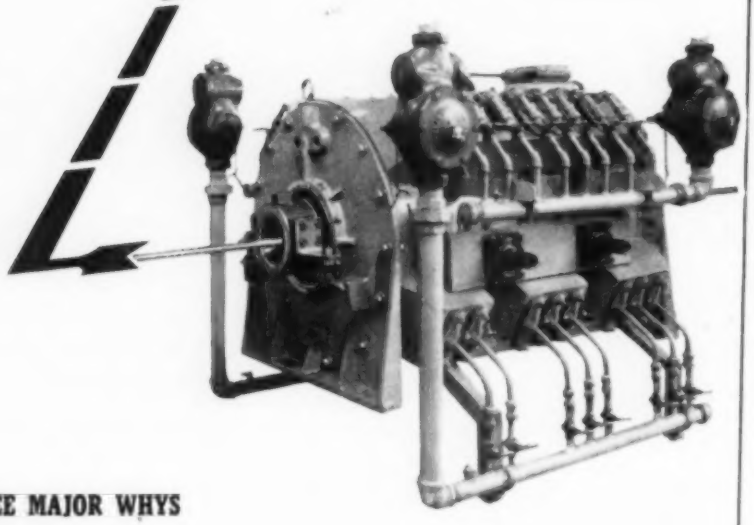


• more about "single-file non-stop heat treatment"

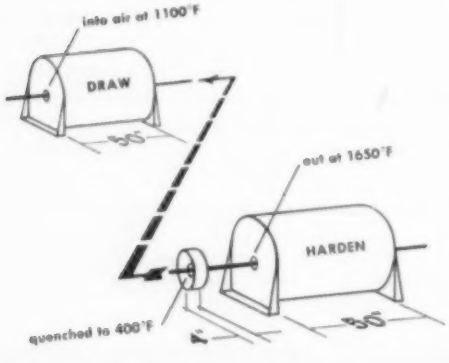
harden & draw on the run



with gas firing — in only 100 inches of furnace and 4 inches of spray quench



THREE MAJOR WHYS



Every section of every length follows precisely the same path—for the same time-temperature treatment.

Time-under-heat is reduced from hours to minutes—and minutes to seconds. (In the job illustrated, no section of metal lingers in either unit for more than 80 seconds.)

Different sizes and shapes of stock may be handled—by simple adjustment of rod-speed and firing-rate, or both. (In the units above, ⅜" to 1½" dia. stock is processed.)

If you can transfer heat into the product fast enough, you can achieve surprising results on the production line. Take the case of a western pre-heat-treated stock mill.

By packing enormous heat releases into small spaces, Selas was able, with certain sizes and steels at least, to harden and draw on the run. In the pilot plant shown, 1" rod is uniformly heated to 1650°, quenched to 400°, and reheated to 1100°, all during continuous movement at 40 inches per minute through a scant 100 inches of furnace. Length follows length, end after end, for smooth non-stop production to the tune of 525 lbs. of steel per hour.

In the combustion cell which does the hardening job, no less than 32 all-ceramic radiant-cup burners vent the full wrath of 1500 cubic feet of gas per hour in a "hell-hole" only 37 inches long by 6 inches across. That's liberating heat at the rate of two million BTU per hour per cubic foot of internal cell volume. Cell wall temperatures up to 2850° are developed—only 3 inches from the traveling rod—and in a complete sleeve around it.

Investigate the metallurgy of speed-heating with your production—perhaps it, too, can be heat treated on the run.

SELAS CORPORATION OF AMERICA PHILA 34 PA
CONSULTING AND MANUFACTURING GAS ENGINEERS

Brazing

(Cont. from page 483) braze a p
containing several miles of joi
Intricate assemblies which wo
require many machine hours
be made of sheet, extrusions, tub
and screw machine parts
brazed in one operation, result
in substantial savings in mater
time and manpower.

Second, furnace and flux b
brazing operations lend themsel
to mechanization and hence
many cases to the use of fewer
less experienced operators. P
duction rates are high, number
type of joints per assembly
almost limitless, and rejections
fewer.

Third, brazed parts requi
practically no finishing of the joi
since the brazing alloy tends
assume a neat, symmetrical fo
Since the whole assembly is hea
during furnace and flux bath br
ing, distortion is kept to the v
minimum.

These advantages may be su
marized as follows:

1. Parts can be brazed wh
are impossible to fabricate by ot
methods.

2. An unlimited number
joints can be made in one assemb

3. Production rates are high

4. Production costs are low.

5. Distortion is at a minimum

6. Practically no finishi
other than flux removal, is require

A careful consideration of joi
design, tooling costs, furnace op
ation costs, final finishing costs a
production volume is requir
before a decision can be made
install the necessary equipment f
carrying out furnace or flux ba
brazing operations. Many ite
have shown substantial advanta
in overall cost for such brazi
over manual gas welding — and,
some cases, over manual tor
brazing. Savings of fifty to o
have been made by brazing o
welding in certain mass produc
parts. Each type of constructio
at this stage of aluminum brazi
must be carefully analyzed co
wise, however, before changes
present procedure are made. Wh
an entirely new item is concern
and must be produced, the adva
tages of brazing are sometim
more evident at the outset.

THE BIRD WITH THE 16-MILE TAIL

The wire you see with the parachute on the end of it is a telephone wire, being payed out from a C-47 cargo plane.

Bell Telephone Laboratories, working with the Air Technical Service Command of the Army Air Forces, developed this idea. It will save precious lives and time on the battlefield.

A soldier throws out a parachute with the wire and a weight attached. The weight drops the line to the target area. From then on, through a tube thrust out the doorway of the plane, the wire thrums out steadily — sixteen miles of it can be laid in 6 2/3 minutes. Isolated patrols can be linked quickly with headquarters. Jungles and mountain ranges no longer need be obstacles to communication.

This is in sharp contrast to the old, dangerous way. The laying of wire through swamps and over mountains often meant the transporting of coils on the backs of men crawling through jungle vegetation, and in the line of sniper fire. It is reported that in one sector of the Asiatic theater alone, 41 men were killed or wounded in a single wire-laying mission.

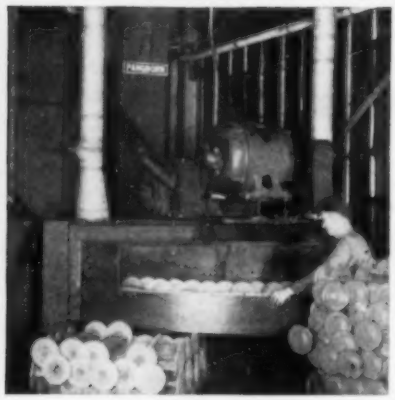
Bell Telephone Laboratories is handling more than 1200 development projects for the Army and the Navy. When the war is over, the Laboratories goes back to its regular job — helping the Bell System bring you the finest telephone service in the world.

BELL TELEPHONE LABORATORIES

Exploring and inventing, devising and perfecting for the Armed Forces at war and for continued improvements and economies in telephone service.

CLEANS FAST!

ROTOBLAST* BARREL



ROTOBLAST* TABLE

SPEED lowers cost—increases tonnage—saves abrasive and power

BLAST CLEANING played an important part in the successful production of bombs and shells and tanks and ships for this war. The main objective of the metal industry has been to *speed* production of *better* products. Pangborn engineers provided both Air and Airless equipment to do this job. Industry uses these modern machines to increase speed as much as 300 percent over previous records.

For post-war requirements, other considerations, not so essential as speed, will be of primary interest to businessmen who again will think in terms of costs and profit. Investigation will show that Pangborn Barrels and Tables and Special Machines clean more work per hour at less cost per ton; use less abrasive per ton of work cleaned because pneumatic and gravity operation, featured only by Pangborn, insures continuing re-use of steel shot or grit without waste until every particle is completely worn away; few operating parts and direct transmission of power insure lowest electrical consumption; and man-power is at minimum because one operator does all the work.

For detailed description and data—write for Bulletins.

**Trade mark of Pangborn Corporation*

PANGBORN

WORLD'S LARGEST MANUFACTURER OF DUST COLLECTING AND BLAST CLEANING EQUIPMENT

PANGBORN CORPORATION • HAGERSTOWN, MD.

Deoxidizing

(Continued from page 504)

allows it to pick up more oxi from the slag.★

It should be mentioned he that quite often the slag arou the outside walls of the furna will have turned a pea green co and have thickened up while t slag in the center of the furna around the electrodes is still dark color. However, if the melt will take his slag sample from t slag close to an electrode and t color of such slag is right, there little worry that the steel is not correct condition; the silico-ma ganese, manganese, and silico additions will certainly result sound steel. As shown above, wh ferrosilicon is added to the furna first, the reaction products are n as fluid as those which are form when the primary deoxidizer silico-manganese. Since they a not fluid they will not coalesce an rise out of the steel. Therefo the silicon-killed steel will ha more inclusions left in it when is solid than will the steel whic has been killed by silico-manganes

It might seem that if a mang nese addition were made to t metal and then followed by addition of ferrosilicon, the would be a good chance of formin a manganese silicate which woul be fluid at this temperature an eliminate itself from the bath. I such a plan the manganese whic is added first should form manga nese oxide particles in the stee while the silicon added later, bein a stronger deoxidizer than manga nese, should be able to take th oxygen from the manganese oxid particles and form silicon dioxid which would join with the ma ganese oxide to form a fusible com pound. However, such does no seem to be the case. A steel deox idized in this manner will not b any cleaner than one which i deoxidized by ferrosilicon, no will it have any better physica properties. Either method is infe rior to the one where the silico manganese is added, followed by manganese addition, and a ferro silicon addition made last to brin the metal to specification.

★Simultaneous addition of ferro silicon and ferromanganese is preferre by some melters over the use of silico manganese. Good results come from additions that leave a residual of 0.15% Si and 0.35% Mn. This steel will giv a solid test.